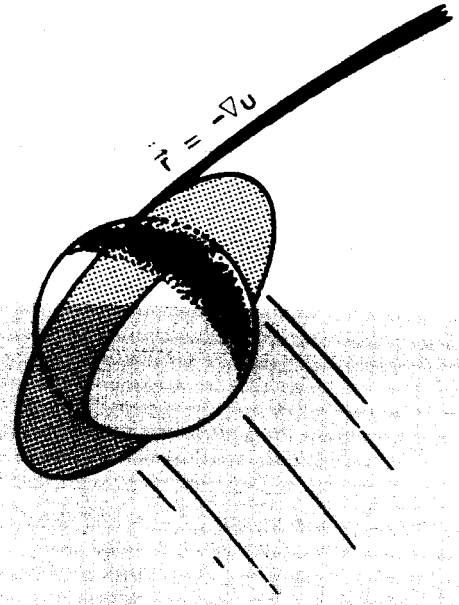
MISSION ANALYSIS OFFICE TECHNICAL STUDY

GALACTIC PROBE TRAJECTORY PARAMETERS— 1969 TO 1972 LAUNCH OPPORTUNITIES



GALACTIC PROBE

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FEBRUARY 17, 1966

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ABSTRACT

This paper presents the results of a study to determine the variation of some important mission parameters with launch date.[1] It also serves to extend some previous work reported by this Office[1] by examining in more detail the flight dynamic characteristics of a Jovian mission. The following launch opportunities that were found in the study reported in reference 1 were investigated:

November 1, 1969 to February 28, 1970
December 1, 1970 to March 18, 1971
January 1, 1972 to April 30, 1972

The required injection velocities, injection energies and corresponding flight times are shown as a function of launch date. These parameters are of fundamental importance in selecting a launch vehicle and payload for the mission. In addition, the geometric relationship between the Sun, probe, and Earth at Jupiter arrival are presented as a function of flight time and launch date.

The results of the study indicate that a mission of nearly 500 days is attractive because launching on the date requiring the minimum injection velocity also provides nearly minimum communications distance at arrival. None of the other flight times displayed this feature.

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[1] See references 1, 2, and 3

Jan Feb. 66

LIST OF ILLUSTRATIONS

Introduction

The selection of a nominal trajectory and launch date for an interplanetary mission is a continuing process until all known constraints have been considered. The information in this paper is intended to aid in the selection of a launch vehicle, launch date and trip time to Jupiter. The only factors considered thus far are trajectory parameters since no other system constraints are known at this time.

The launch opportunities for the Galactic Probe mission were studied for flight times of 300, 600, 800, and 1,000 days and were reported in reference 1. The present paper utilized the information found in reference 1 and expands the scope to include more detail in the region of 400 to 600 days flight times. These trip times are reasonable limits for the mission because a 300 day mission requires excessive injection velocity and a 700 day mission results in near occultation by the Sun at Jupiter arrival.

Preliminary trajectory information pertaining to design of the communications system was reported in references 2 and 3. The time histories of the Sun-Earth-probe angular relations were shown for three launch opportunities corresponding to a 600 day mission. These data were preliminary in nature intended to support the feasibility of the mission. This paper shows the variation of these same Sun-Earth-probe relationships at Jupiter arrival as a function of launch date and flight time.

List of Symbols

The symbols and nomenclature used in this report are defined below:

$\vec{\rho}$ ---------- Vector from Sun to probe after injection

$\vec{P}$ ---------- Vector from Sun to Earth

$\vec{r}$ ---------- Vector from Earth to probe

$|\vec{r}|$ ---------- Communications distance

$\vec{X}^{\circ} = \dfrac{\vec{X}}{|\vec{X}|}$ ---- A unit vector in general

K_1 ---------- Earth-Sun-probe angle
$K_1 = \text{Cos}^{-1}(\vec{P}^{\circ} \cdot \vec{\rho}^{\circ})$

K_2 ---------- Earth-probe-Sun angle
$K_2 = \text{Cos}^{-1}(\vec{r}^{\circ} \cdot \vec{\rho}^{\circ})$

φ ---------- Sun-Earth-probe angle
$\varphi = \text{Cos}^{-1}(-\vec{\rho}^{\circ} \cdot \vec{r}^{\circ})$

Discussion of Results

The data presented in this report were generated by the digital computer program described in reference 4. The program simulates the motion of a spacecraft using the method of "patched conics" and the data is valid subject to the following assumptions:

1. The spacecraft is acted on by the gravitational force of only one central body at any time.

2. The oblateness effects of the planets are neglected.

3. The spacecraft is injected into the escape trajectory from a 185.2 km (100 nautical miles) parking orbit inclined 28.5 degrees to the Earth's equator.

The results of the study are presented in Figures 1a to 10c. The data can be separated into two categories: (1) flight dynamics and (2) Sun-Earth-probe geometry at closest approach to Jupiter. The geocentric injection velocity is probably the most important dynamic parameter because it can be correlated with launch vehicle performance. Figures 1a to 1c show the variation of injection velocity with launch date and flight time. Figure 2 shows the performance capabilities of five launch vehicles taken from reference 5. The data shown on Figure 2 are meant to be guidlines only and should not be used for detailed mission planning. The following table correlates the payloads, flight times, and minimum injection velocities from the Figures. The information in the table is self explanatory and indicates the launch vehicle and possible payload capability for a specified mission to Jupiter.

Table 1 - LAUNCH VEHICLE CAPABILITIES

Approximate Launch Date	Flight Time Days	Minimum Injection Velocity (km/s)	Approximate Payload (Kilograms) Atlas Centaur TE-364	SLV3X Centaur Kick	Saturn IB Centaur	Saturn IB Centaur Kick
Jan. 10, 1970	400	16.8	*	*	*	900
Jan. 5, 1970	450	15.9	55	250	300	1350
Jan. 3, 1970	500	15.3	90	350	600	1700
Jan. 2, 1970	550	14.9	120	420	800	1900
Jan. 1, 1970	600	14.6	160	500	1050	2200
Feb. 11, 1971	400	16.6	*	140	*	1000
Feb. 7, 1971	450	15.8	65	280	400	1300
Feb. 4, 1971	500	15.2	100	370	700	1800
Feb. 2, 1971	550	14.7	150	470	950	2100
Jan. 30, 1971	600	14.5	170	510	1100	2300
March 15, 1972	400	16.4	*	180	*	1100
March 12, 1972	450	15.6	78	300	500	1500
March 7, 1972	500	15.0	120	400	800	1900
March 5, 1972	550	14.7	150	470	950	2100
March 1, 1972	600	14.4	180	540	1200	2300

*Required injection velocity is beyond the capability of the launch vehicle.

Earth-Sun-Probe Geometry

The selection of an interplanetary trajectory is influenced by the constraints imposed at arrival at the target planet. The Earth-Sun-probe geometry is of fundamental interest because it dictates the communications distances and instances of possible communications blackout put to occultation by the Sun. The most desirable situation is to plan the arrival when Jupiter is in opposition and a minimum injection velocity is required.

The communications distance is plotted versus launch date for various flight times in Figures 7a to 7c. If the data is used in conjunction with the injection velocity on Figures 1a to 1c it can be seen that the 500 day mission offers a distinct advantage over the others because the communications distance at arrival is nearly minimized for minimum injection velocity. The situation is pictured in Figures 6a and 6b which shows examples of the transfer trajectory projected in the ecliptic plane and the geometric relationship of the Earth-Jupiter-Sun-probe during the flight. These plots also clearly point out that flight times of 400 to 600 days are feasible while 700 and 800 day missions are not because of possible communications blackout at Jupiter arrival.

Conclusions

The following conclusions can be drawn from the results of this study:

1. The Galactic Probe mission as presently envisioned is feasible and within the capabilities of the planned launch vehicles in the 1970-1974 time period.

2. In order to minimize the communications distance at Jupiter arrival the total flight time should be about 500 days. This eliminates the possibility of communications blackout due to occultation by the sun.

REFERENCES

1. Coady, R.E., "Launch Opportunities for the Galactic Probe - Early Missions," Mission Analysis Office Technical Study, Goddard Space Flight Center, September 25, 1965.

2. Vonbun, F.O., "Transfer Geometry, Communications Conditions and Definitions for Galactic Probe Analyses," Mission Analysis Office Technical Study, Goddard Space Flight Center, October 4, 1965.

3. Coady, R.E., "Preliminary Trajectory Data to be used in Communications Design for the Galactic Probe," Mission Analysis Office Technical Study, Goddard Space Flight Center, October 20, 1965.

4. "Quick Look Mission Analysis Program" Prepared for Goddard Space Flight Center by Philco Corporation, WDL Division.

5. "Launch Vehicle Estimating Factors," Prepared by Space Science Board, National Academy of Sciences, Summer Study Group, NASA/Office of Space Science and Applications, June 1965.

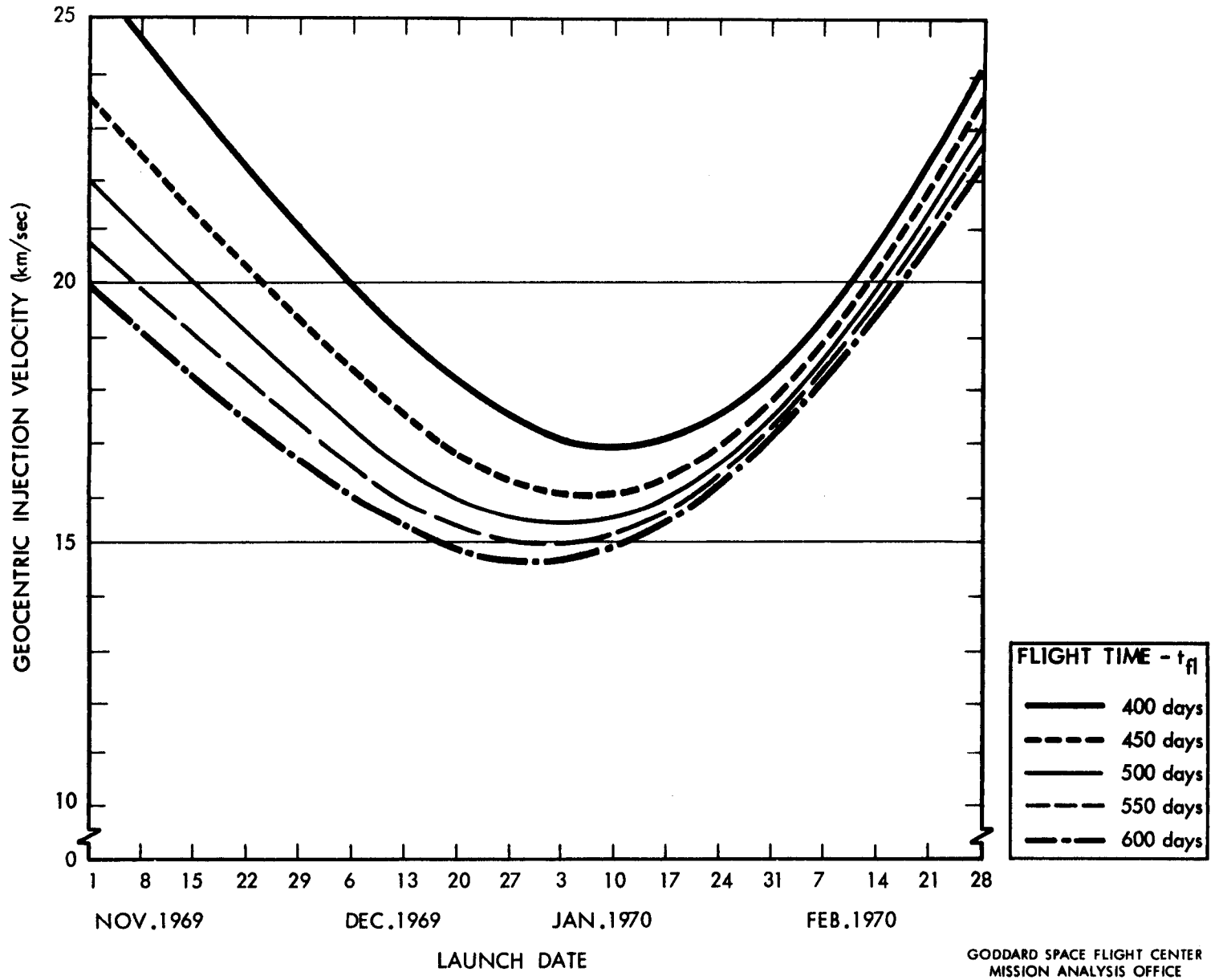

Figure 1a - Geocentric Injection Velocity versus Launch Date
November 1, 1969 - February 28, 1970

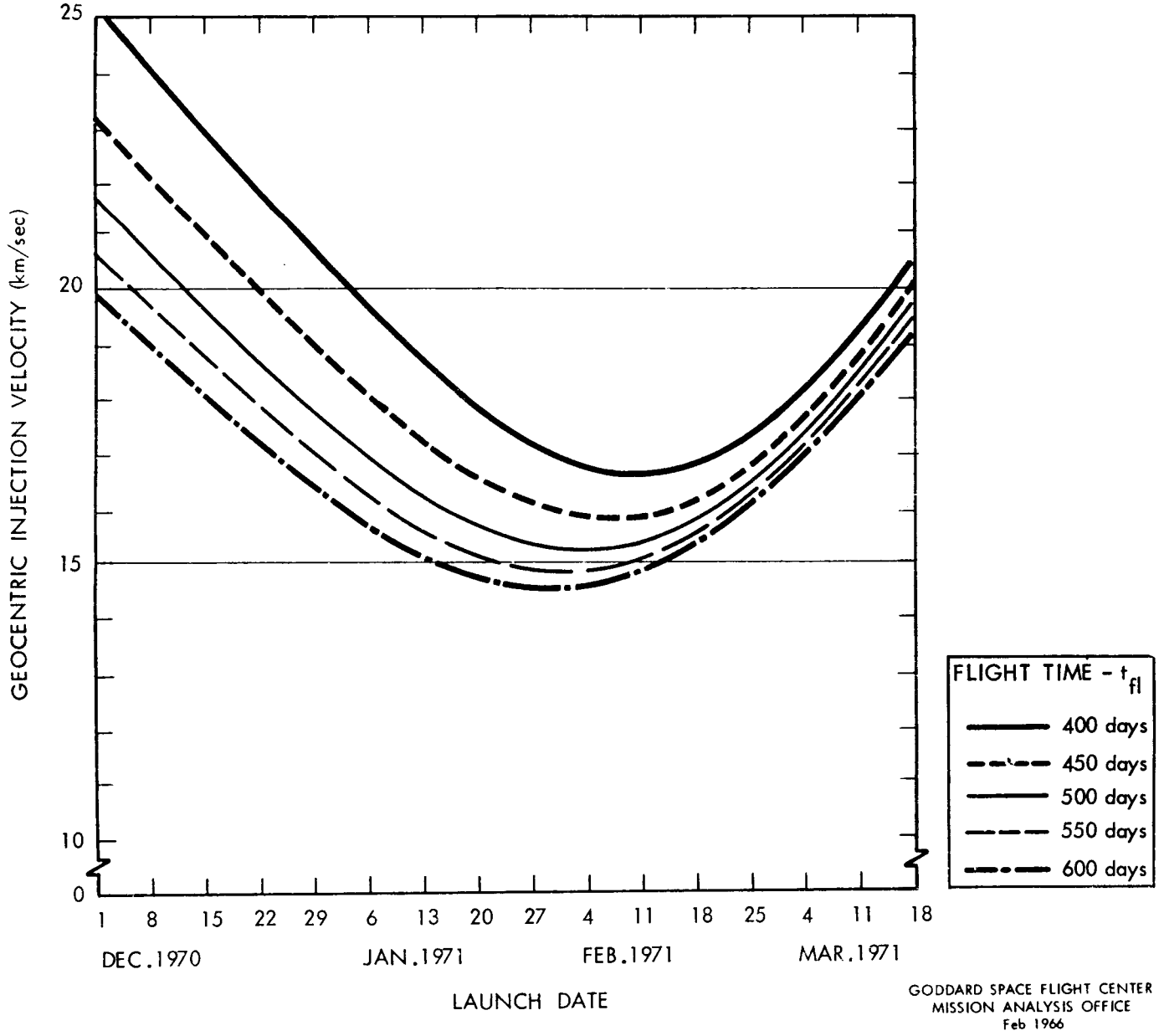

Figure 1b - Geocentric Injection Velocity versus Launch Date
December 1, 1970 - March 18, 1971

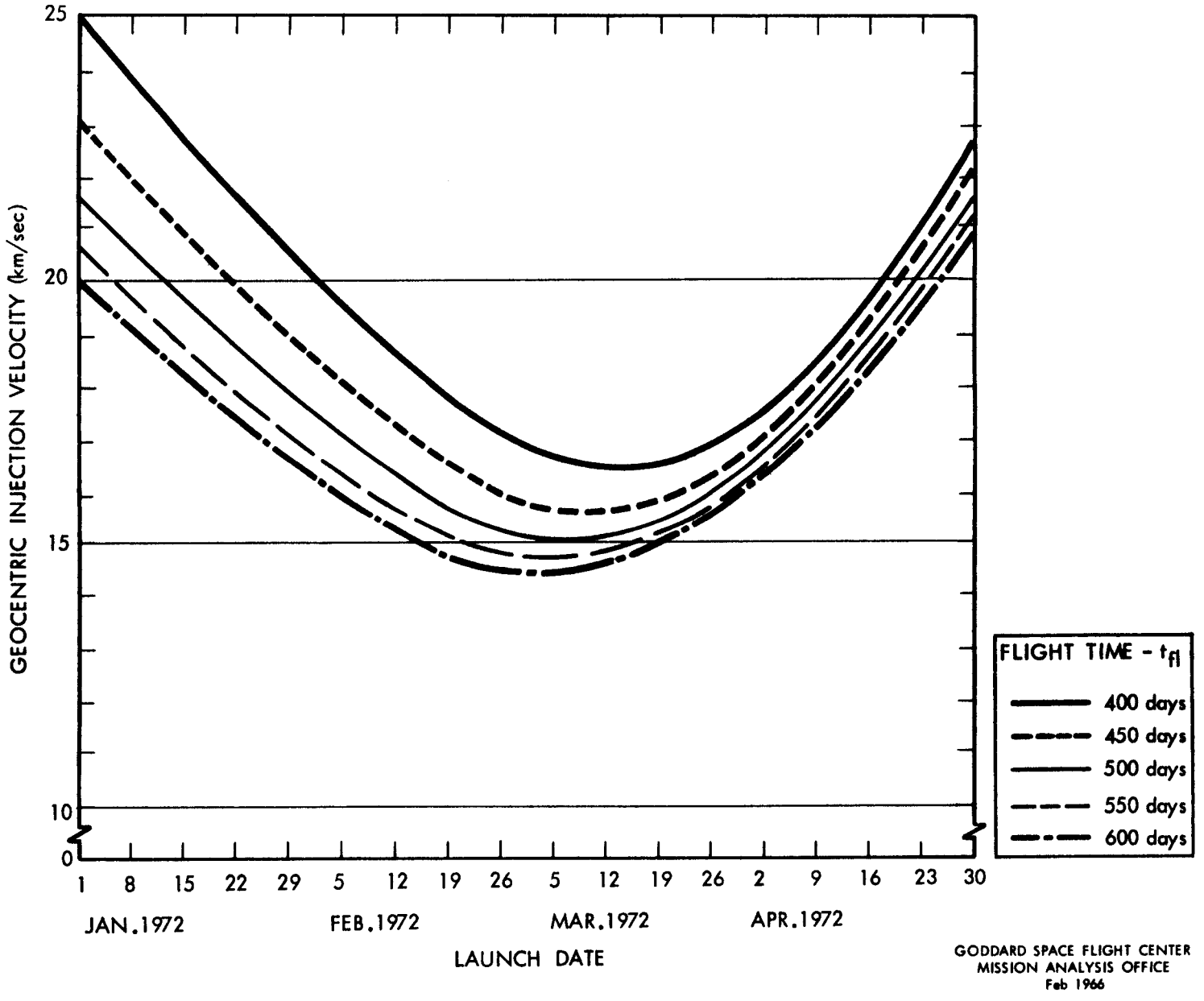

Figure 1c - Geocentric Injection Velocity versus Launch Date
January 1, 1972 - April 30, 1972

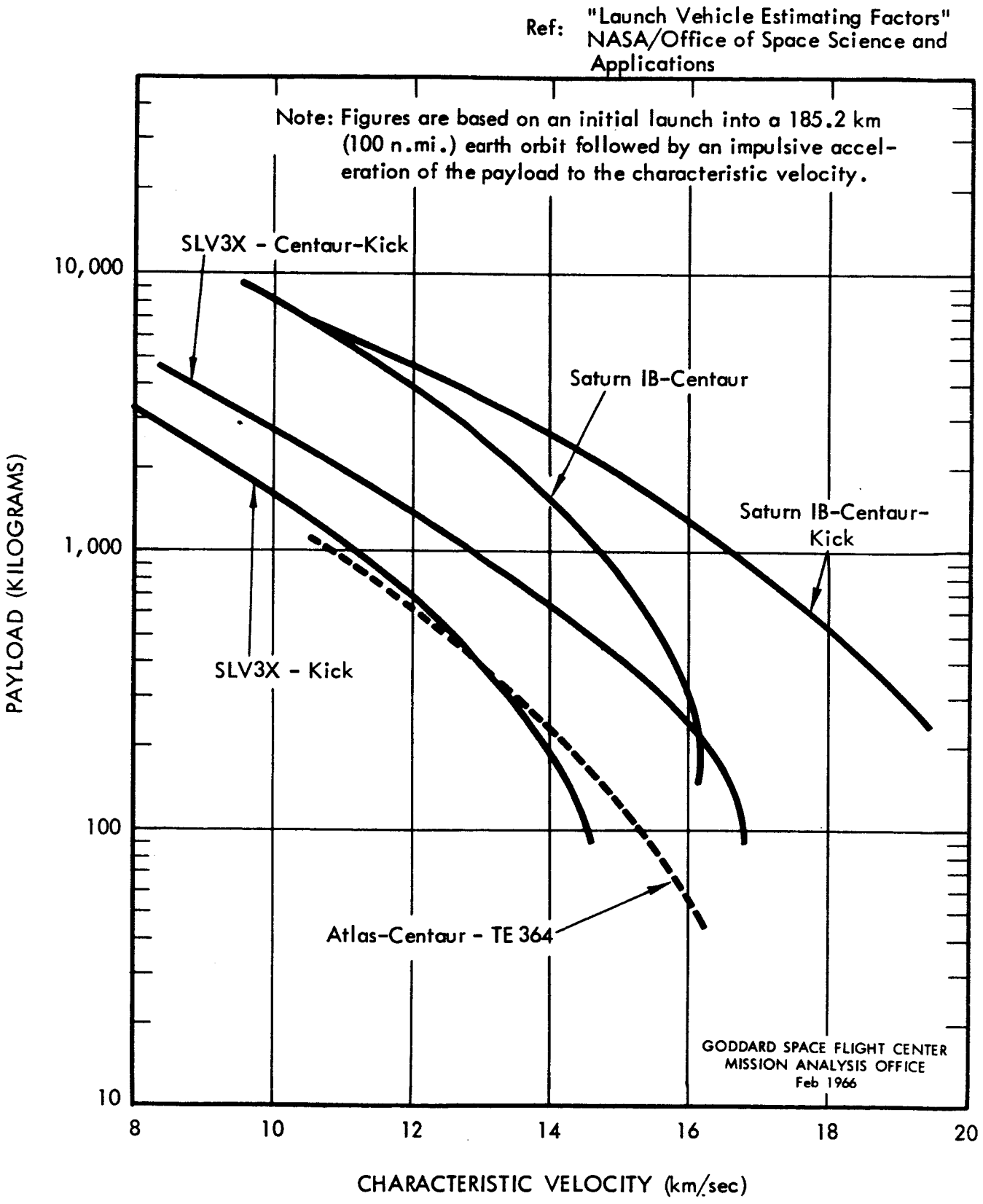

Figure 2 - Launch Vehicle Capabilities (1970 - 1974)

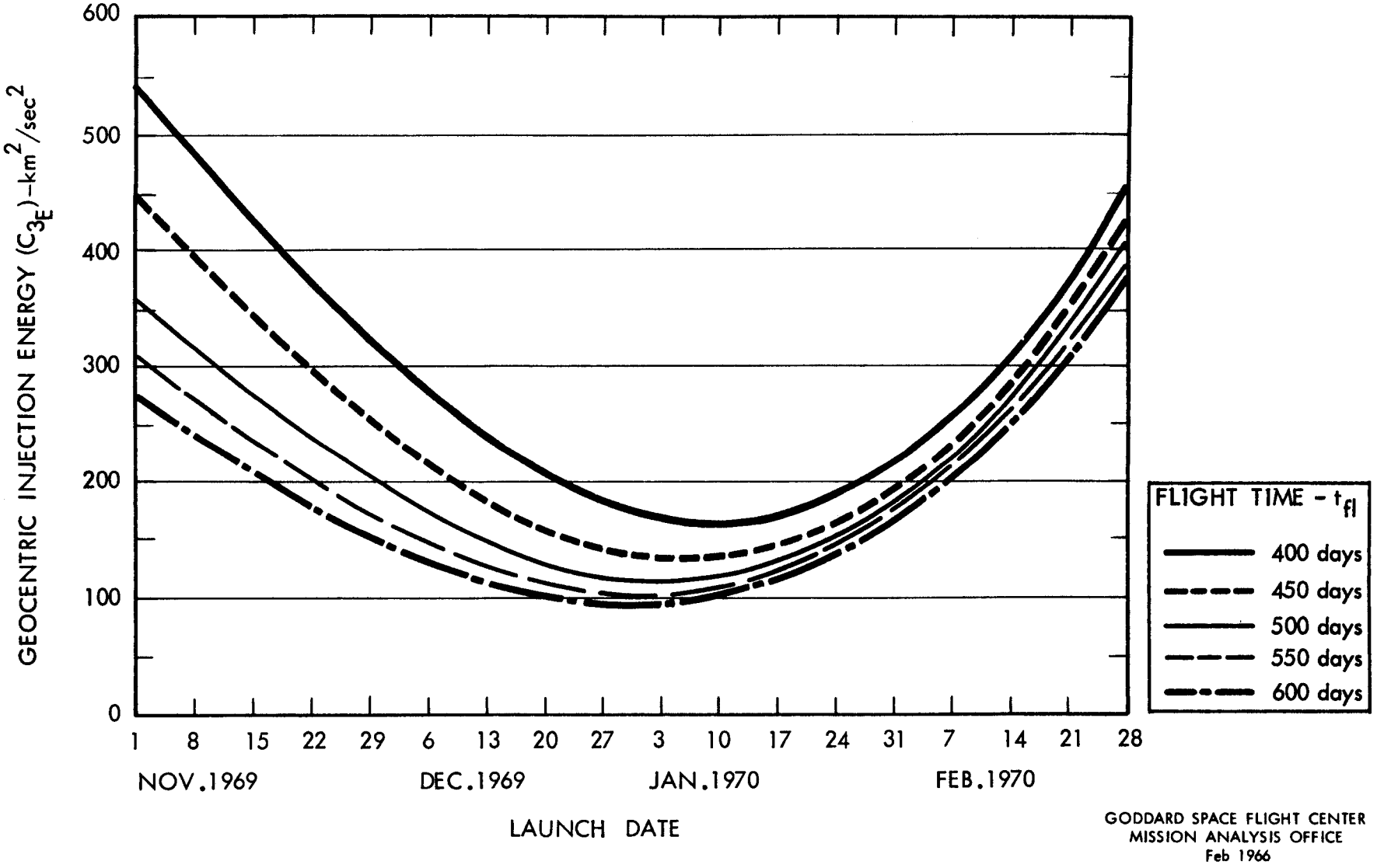

Figure 3a - Geocentric Injection Energy versus Launch Date
November 1, 1969 - February 28, 1970

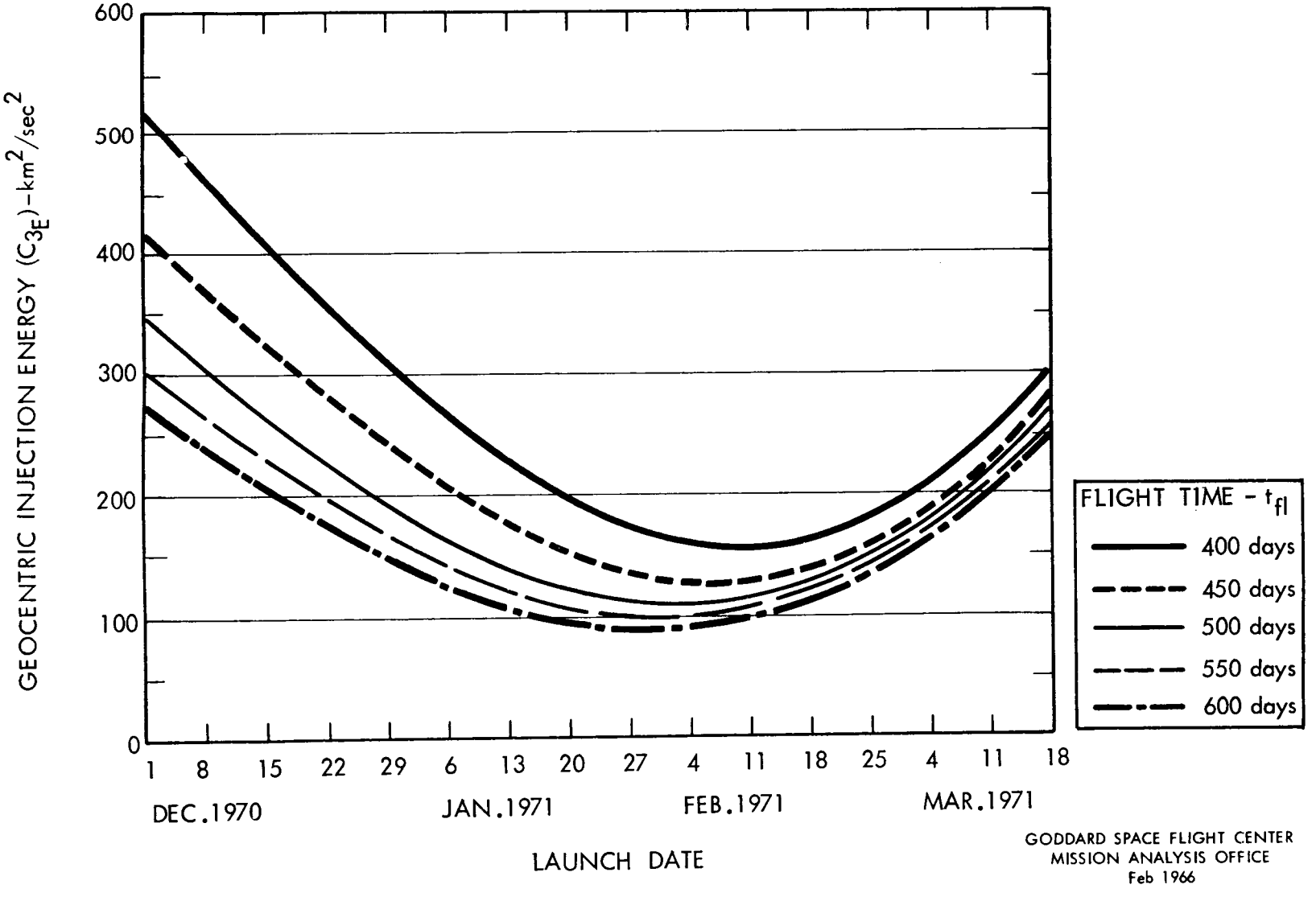

Figure 3b - Geocentric Injection Energy versus Launch Date
December 1, 1970 - March 18, 1971

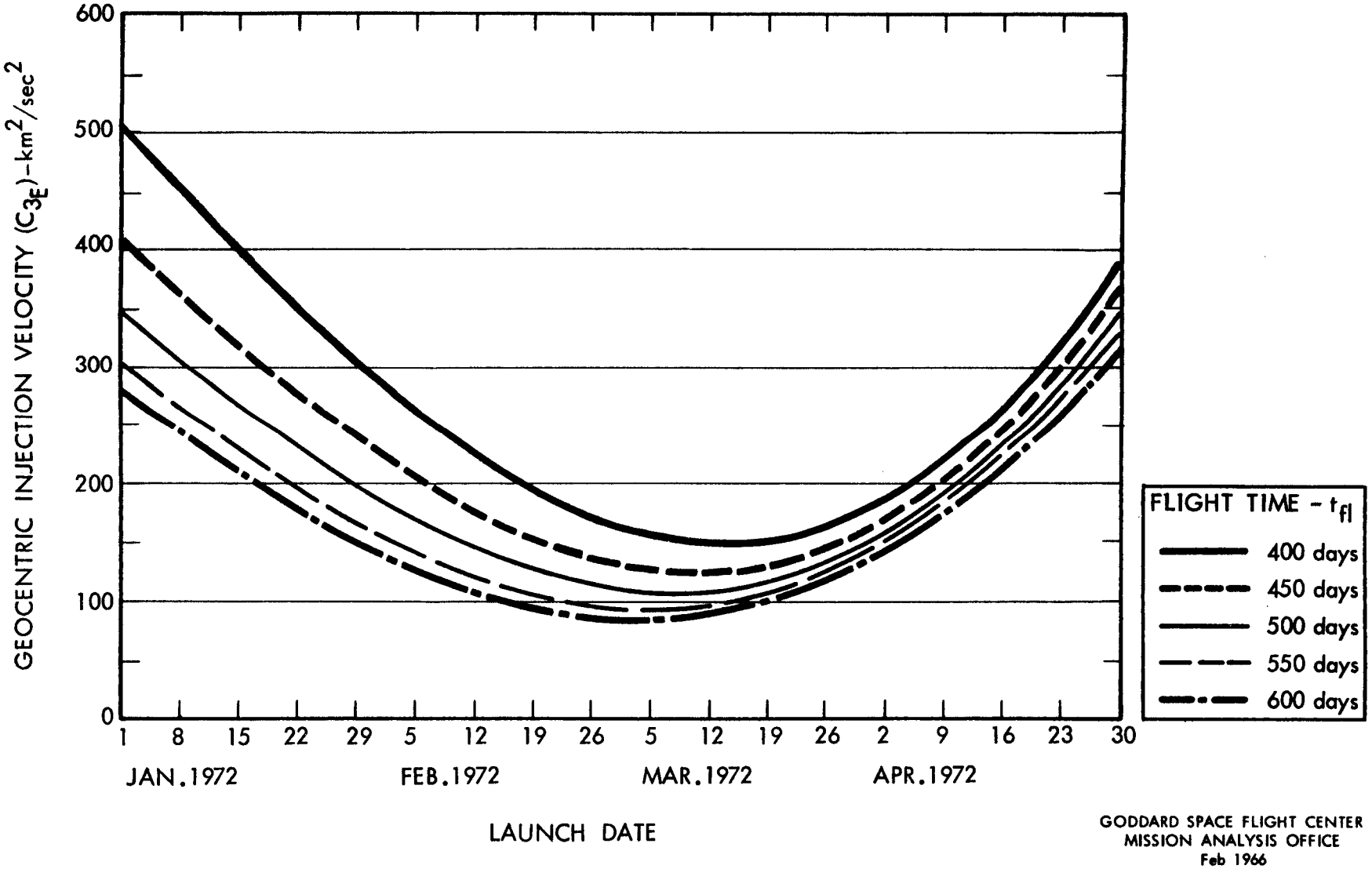

Figure 3c - Geocentric Injection Energy versus Launch Date
January 1, 1972 - April 30, 1972

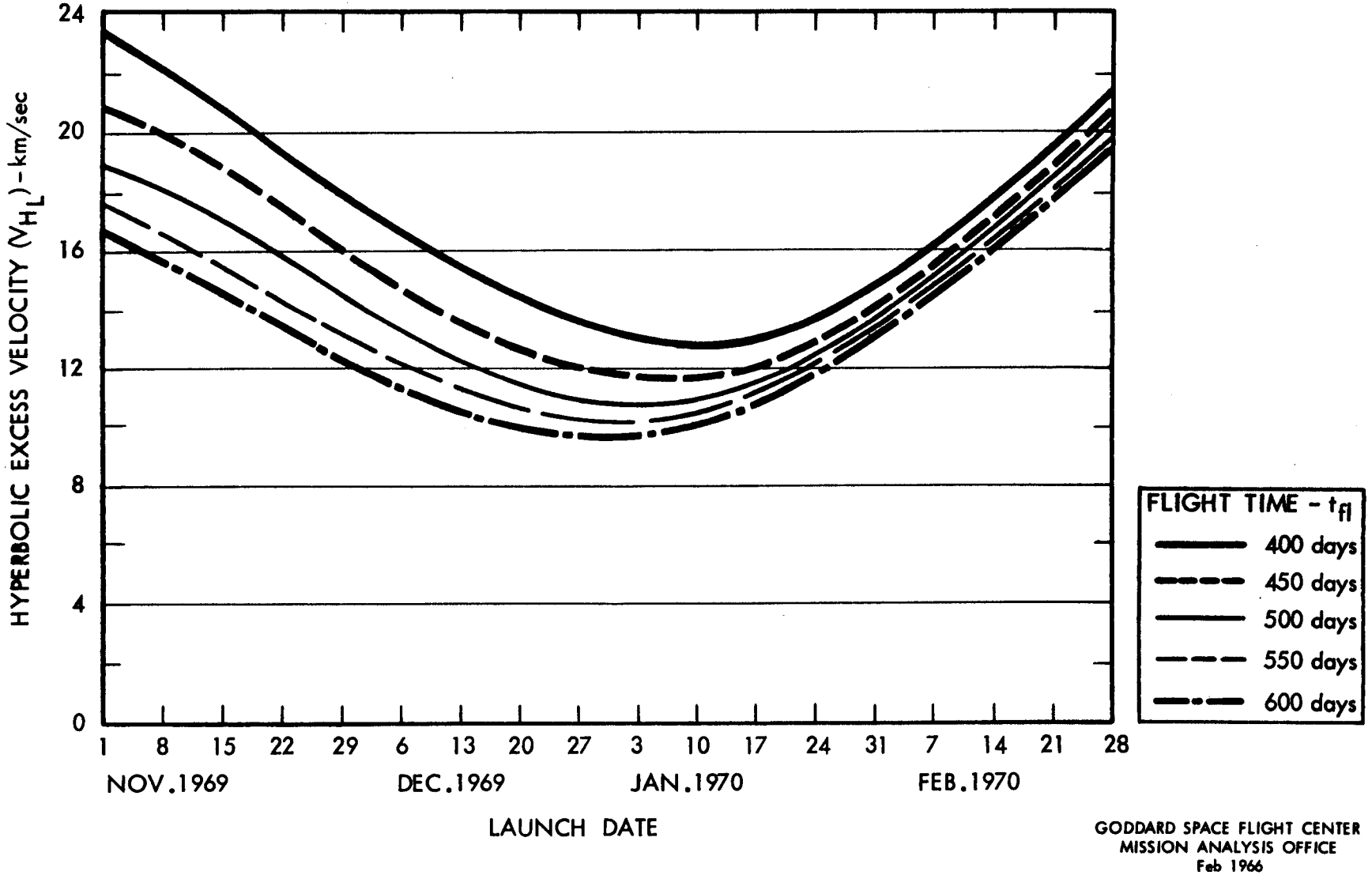

Figure 4a - Injection Hyperbolic Excess Velocity versus Launch Date
November 1, 1969 - February 28, 1970

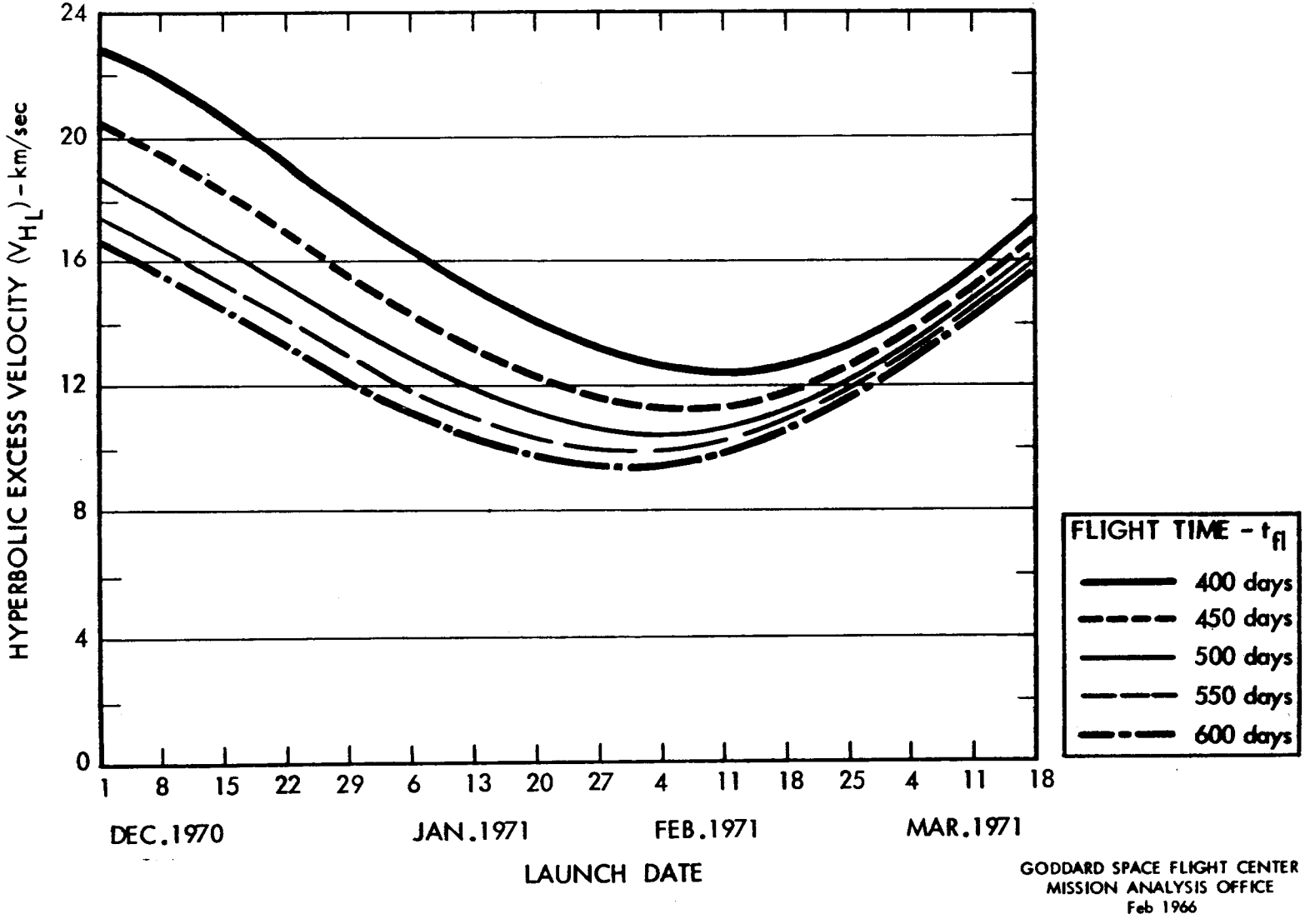

Figure 4b - Injection Hyperbolic Excess Velocity versus Launch Date
December 1, 1970 - March 18, 1971

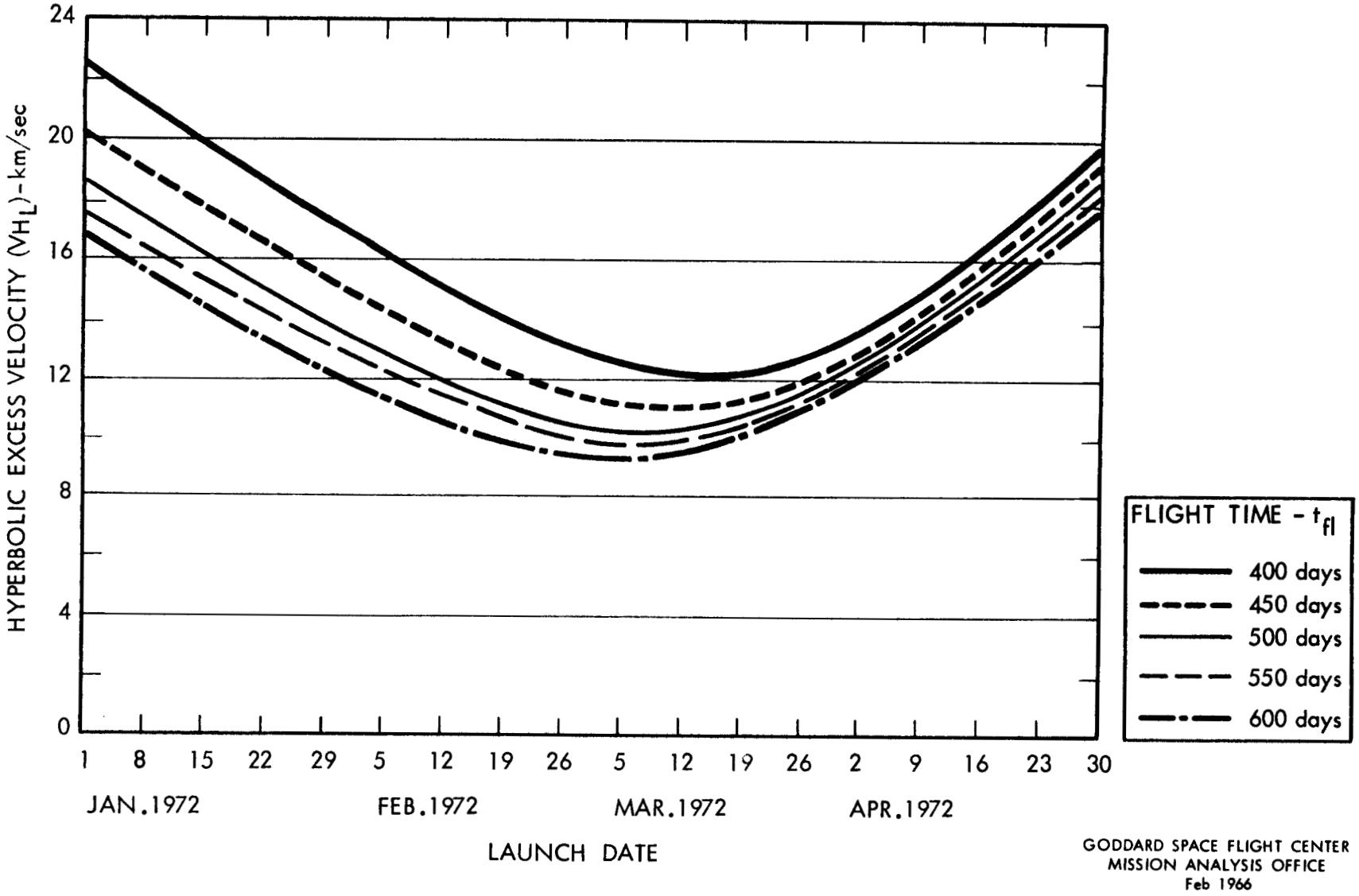

Figure 4c - Injection Hyperbolic Excess Velocity versus Launch Date
January 1, 1972 - April 30, 1972

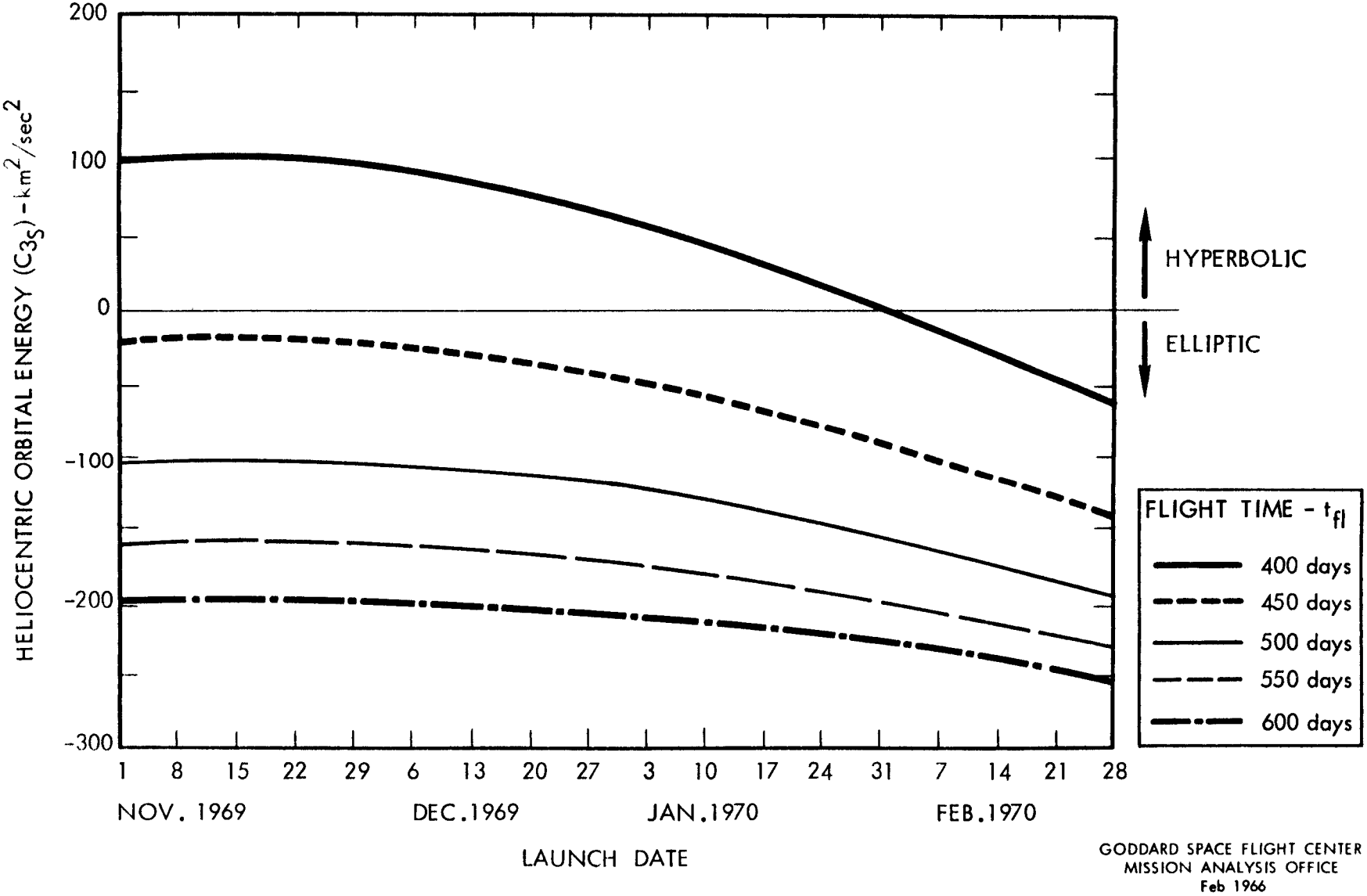

Figure 5a - Heliocentric Orbital Energy versus Launch Date
November 1, 1969 - February 28, 1970

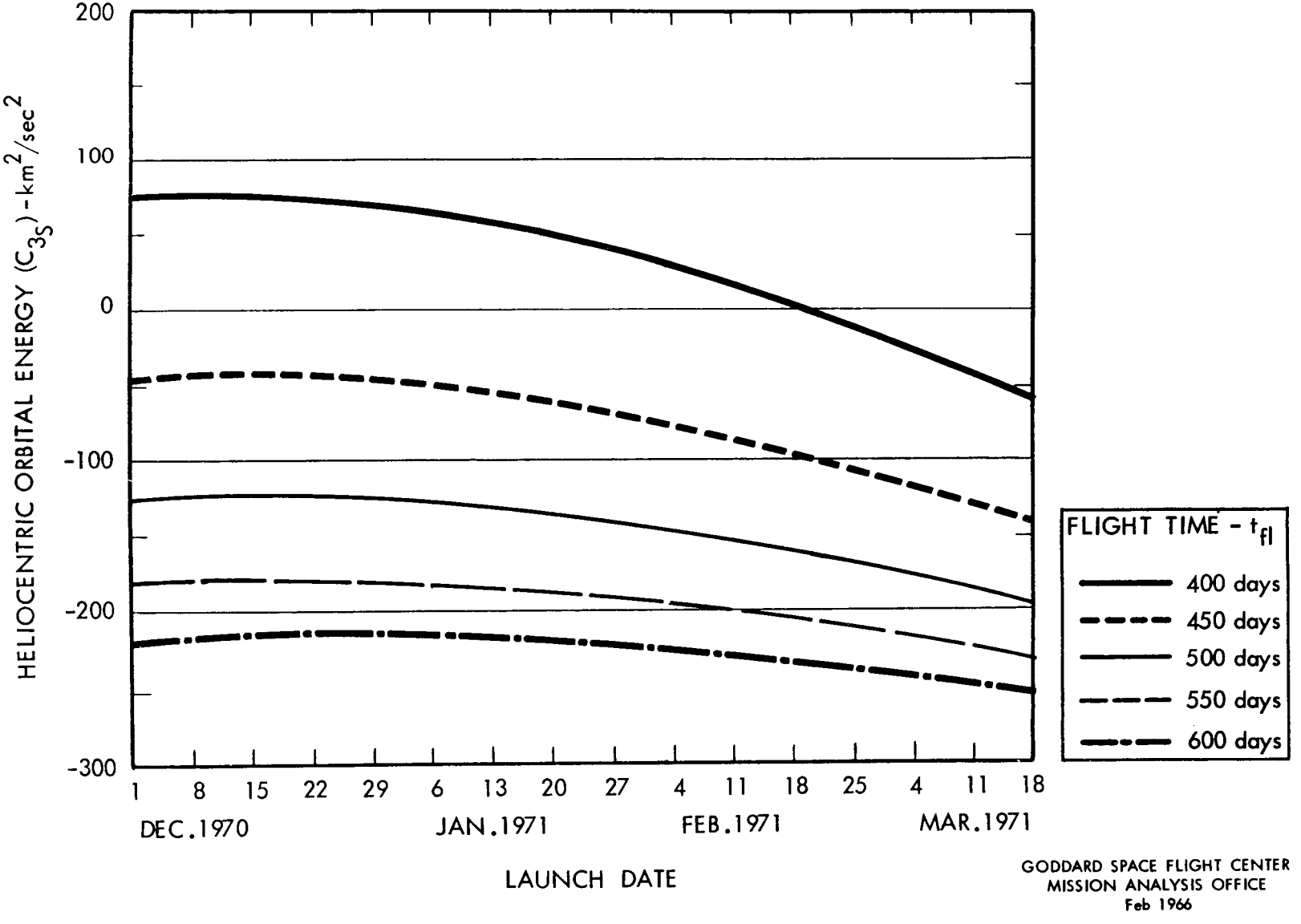

Figure 5b - Hiliocentric Orbital Energy versus Launch Date
December 1, 1970 - March 18, 1971

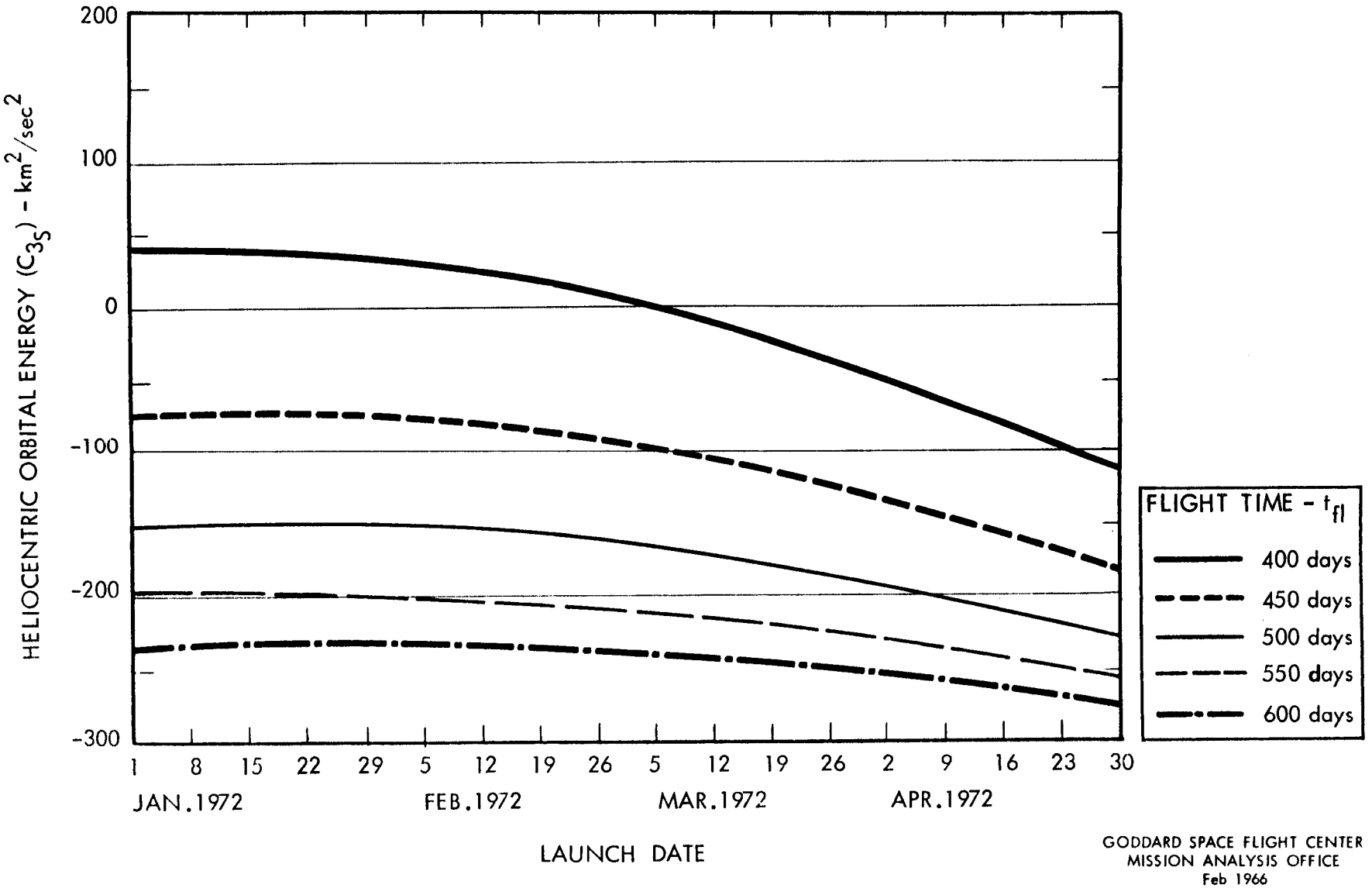

Figure 5c - Heliocentric Orbital Energy versus Launch Date
January 1, 1972 - April 30, 1972

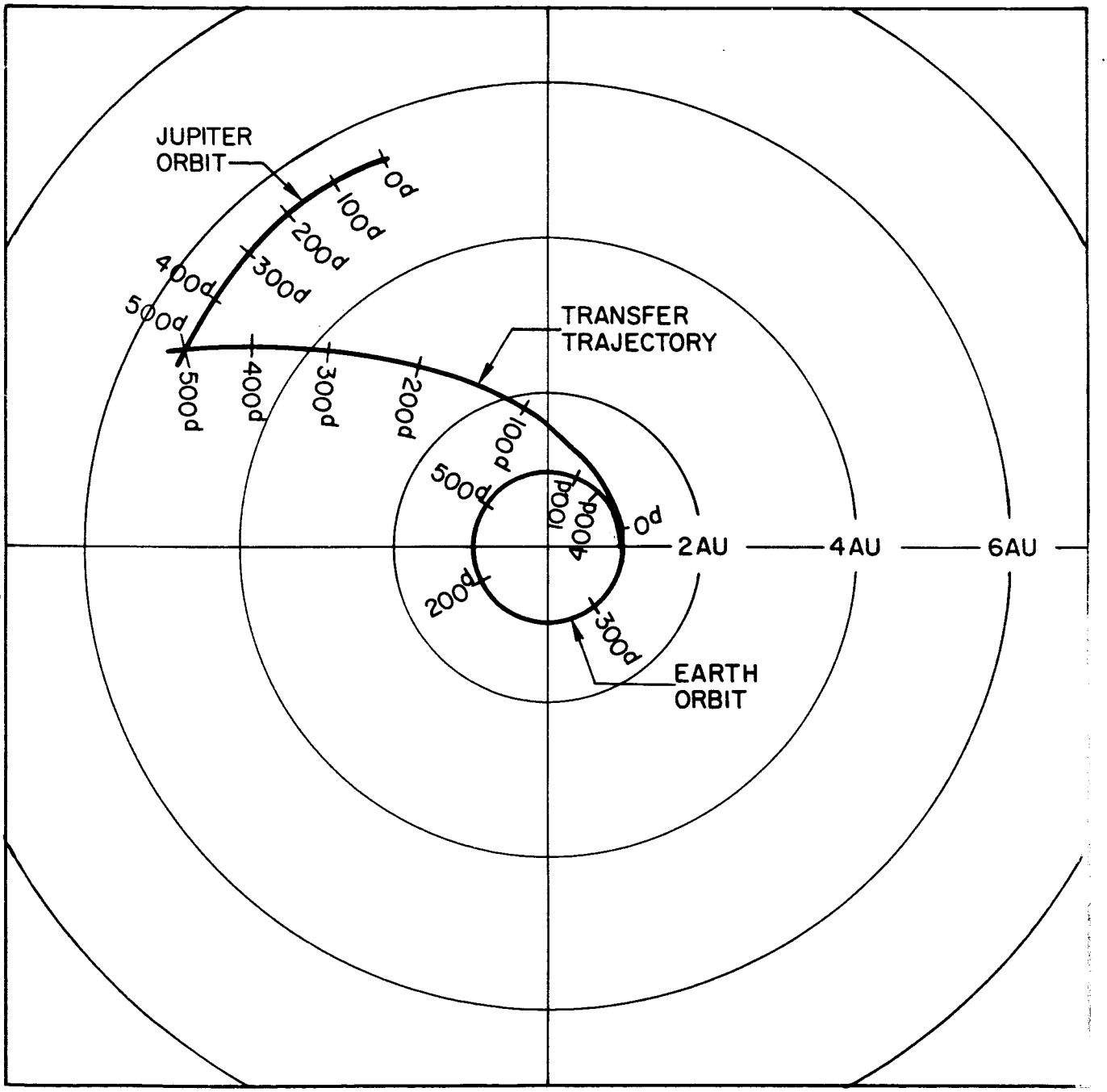

Figure 6a - Ecliptic Projection of an Earth-to-Jupiter Trajectory
Flight Time = 500 days

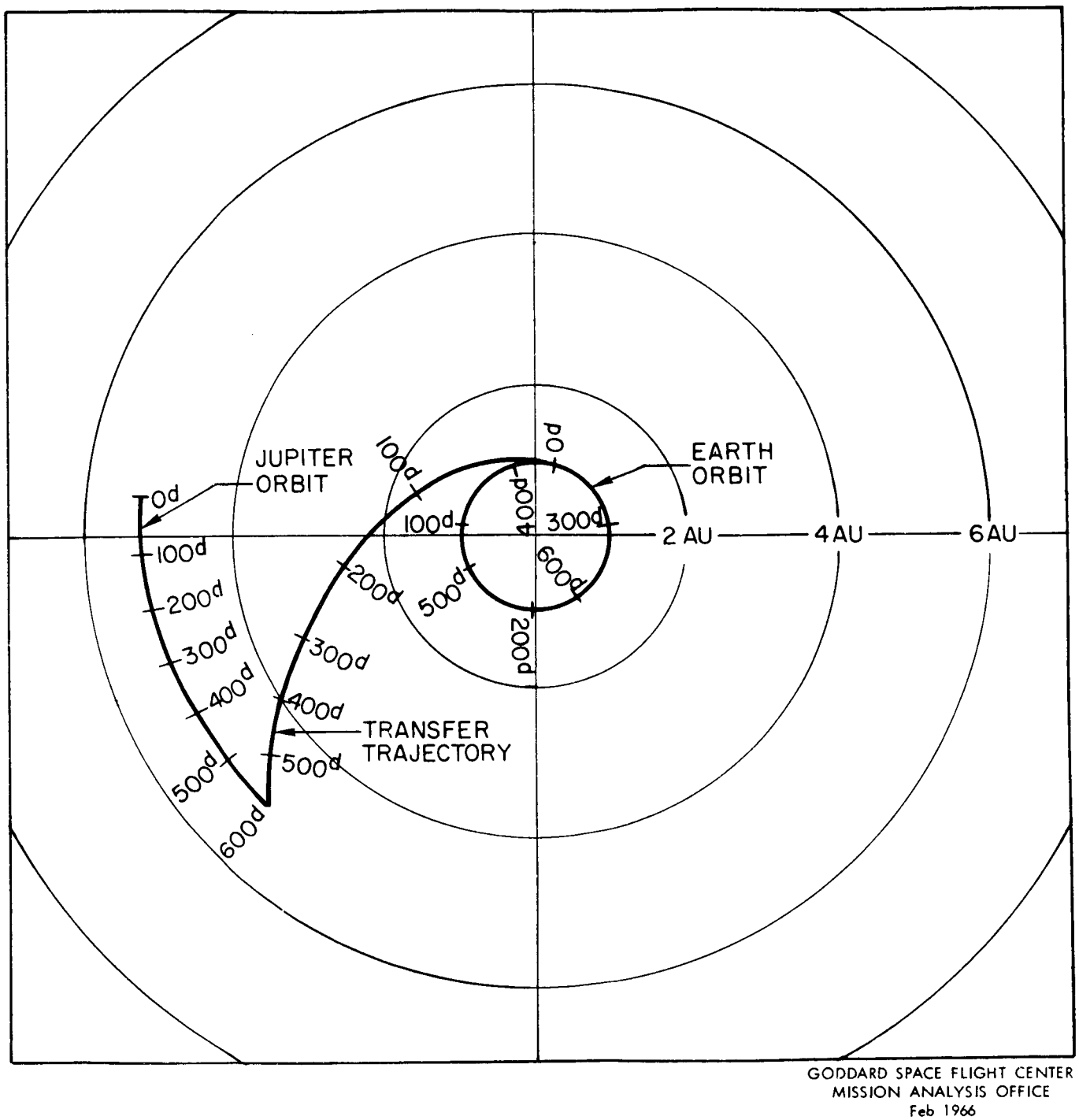

Figure 6b - Ecliptic Projection of an Earth - to - Jupiter Trajectory
Flight Time = 600 days

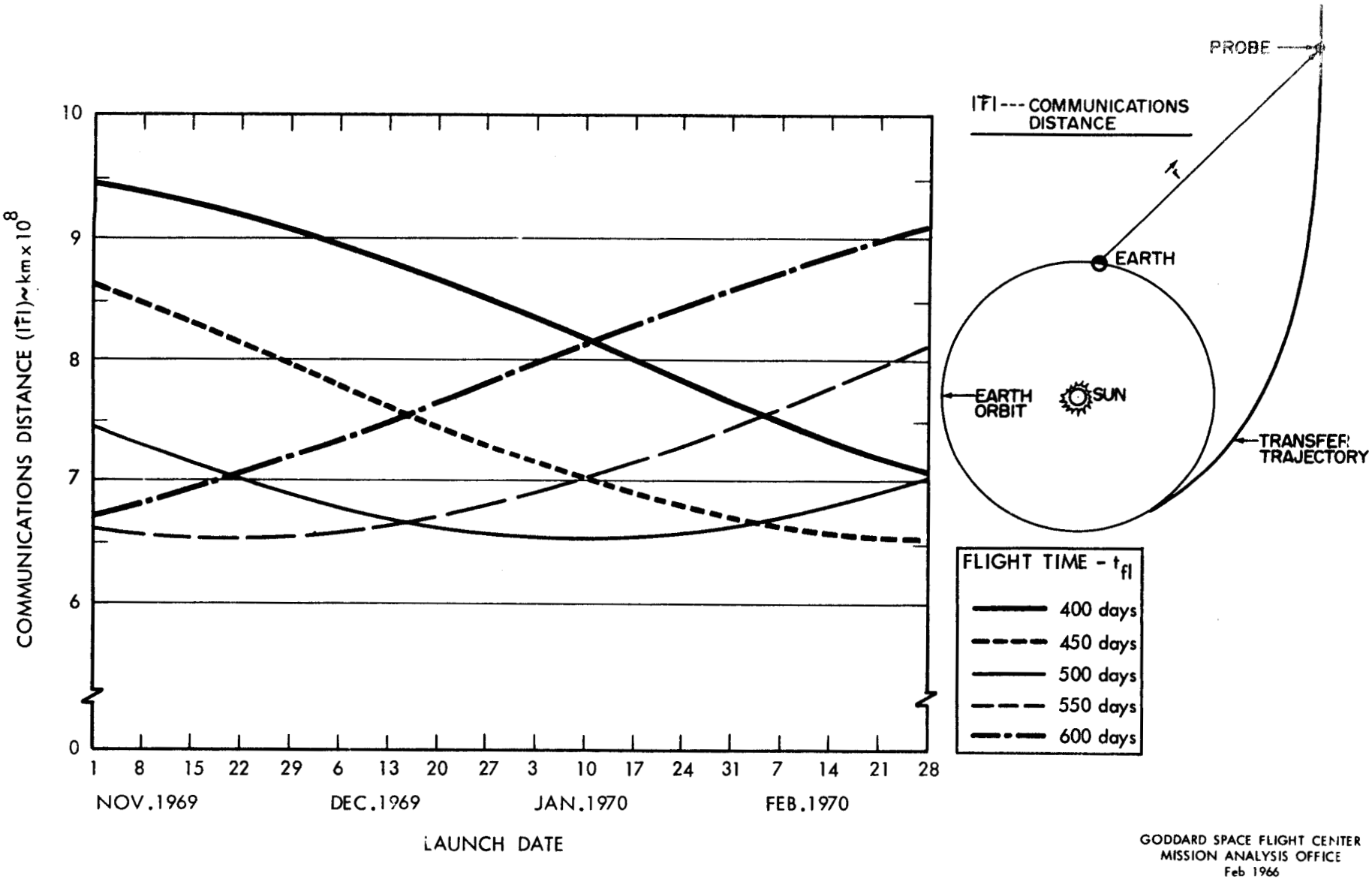

Figure 7a - Communications Distance at Arrival versus Launch Date
November 1, 1969 - February 28, 1970

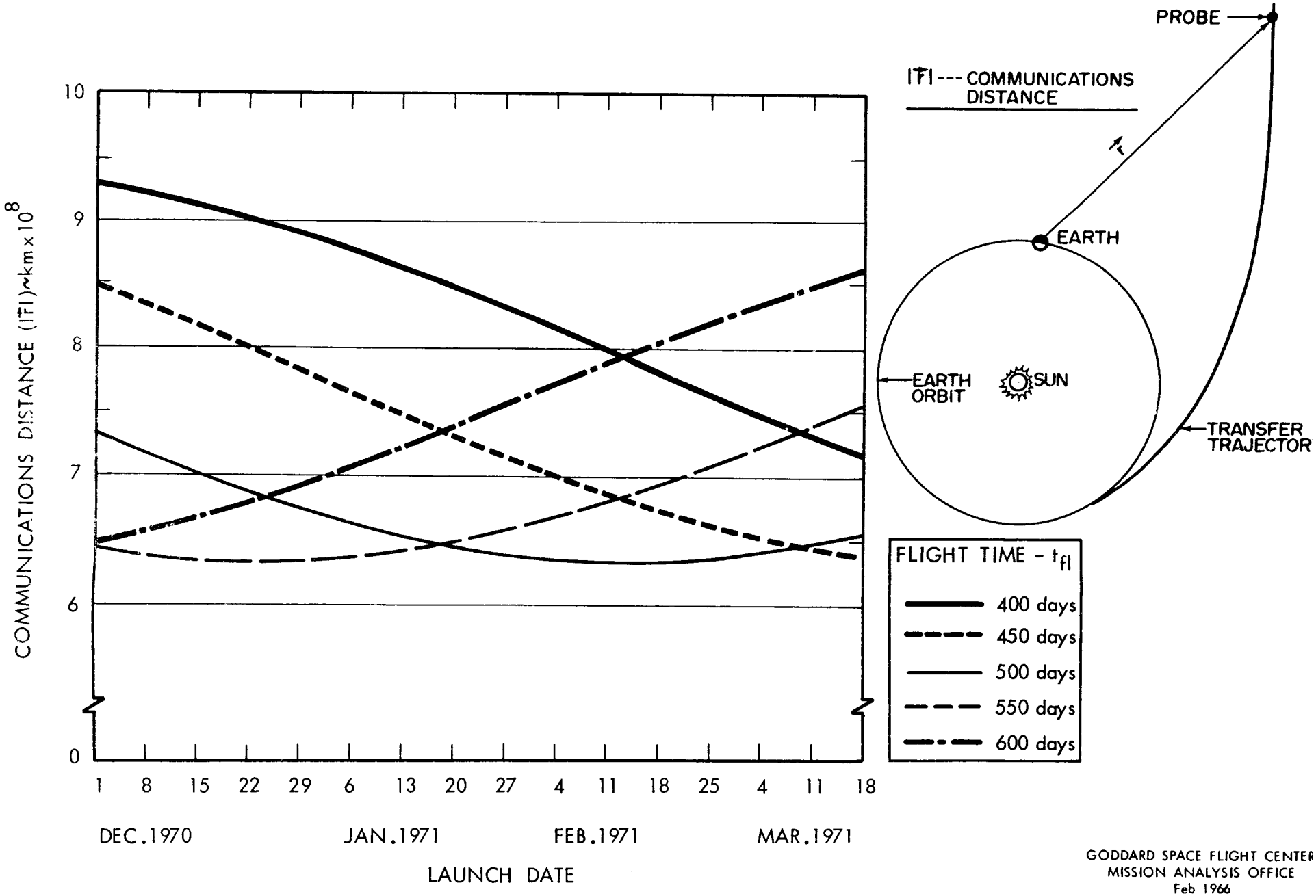

Figure 7b - Communications Distance at Arrival versus Launch Date
December 1, 1970 - March 18, 1971

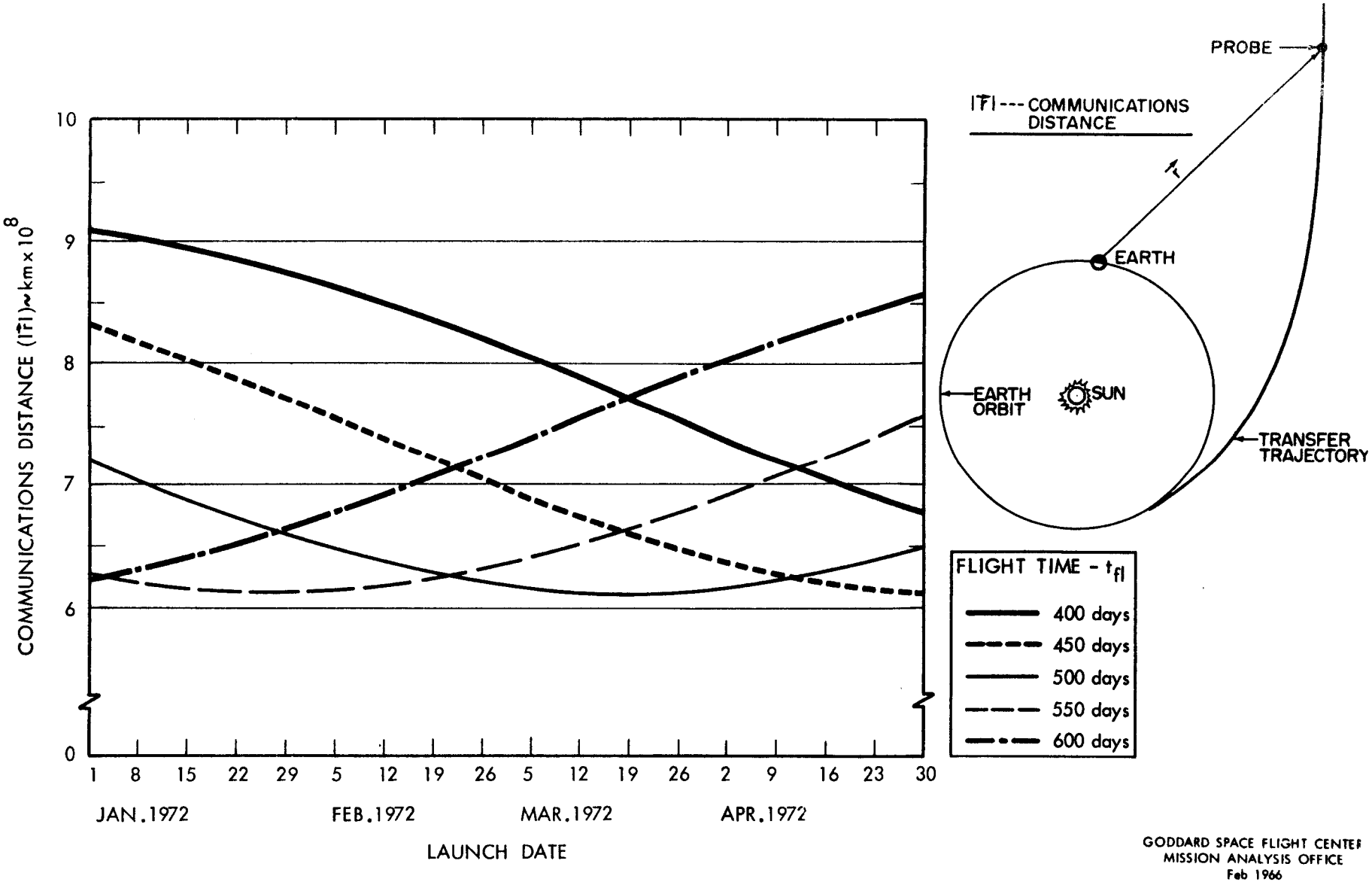

Figure 7c - Communications Distance at Arrival versus Launch Date
January 1, 1972 - April 30, 1972

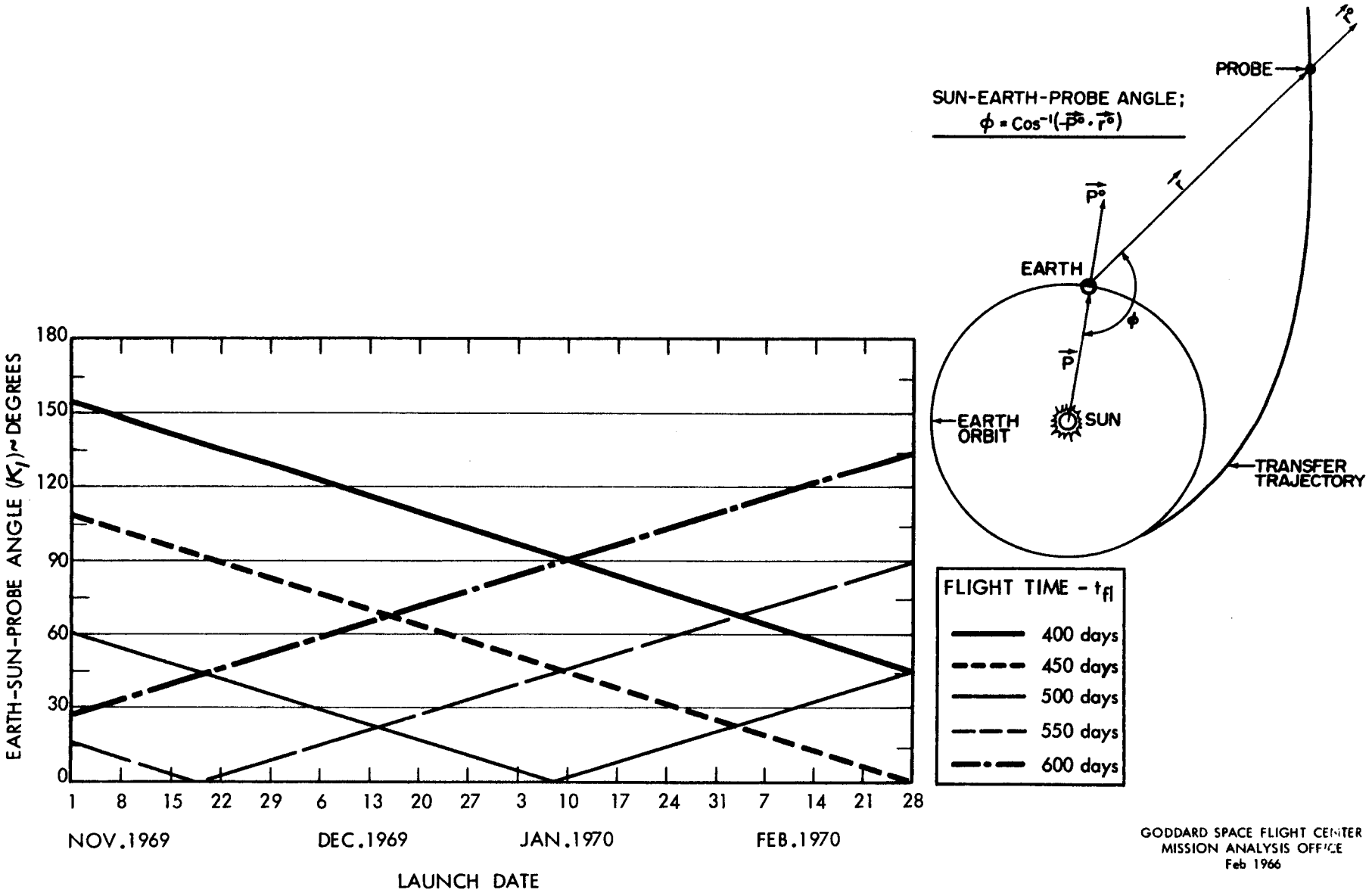

Figure 8a - Earth-Sun-Probe Angle at Arrival versus Launch Date
November 1, 1969 - February 28, 1970

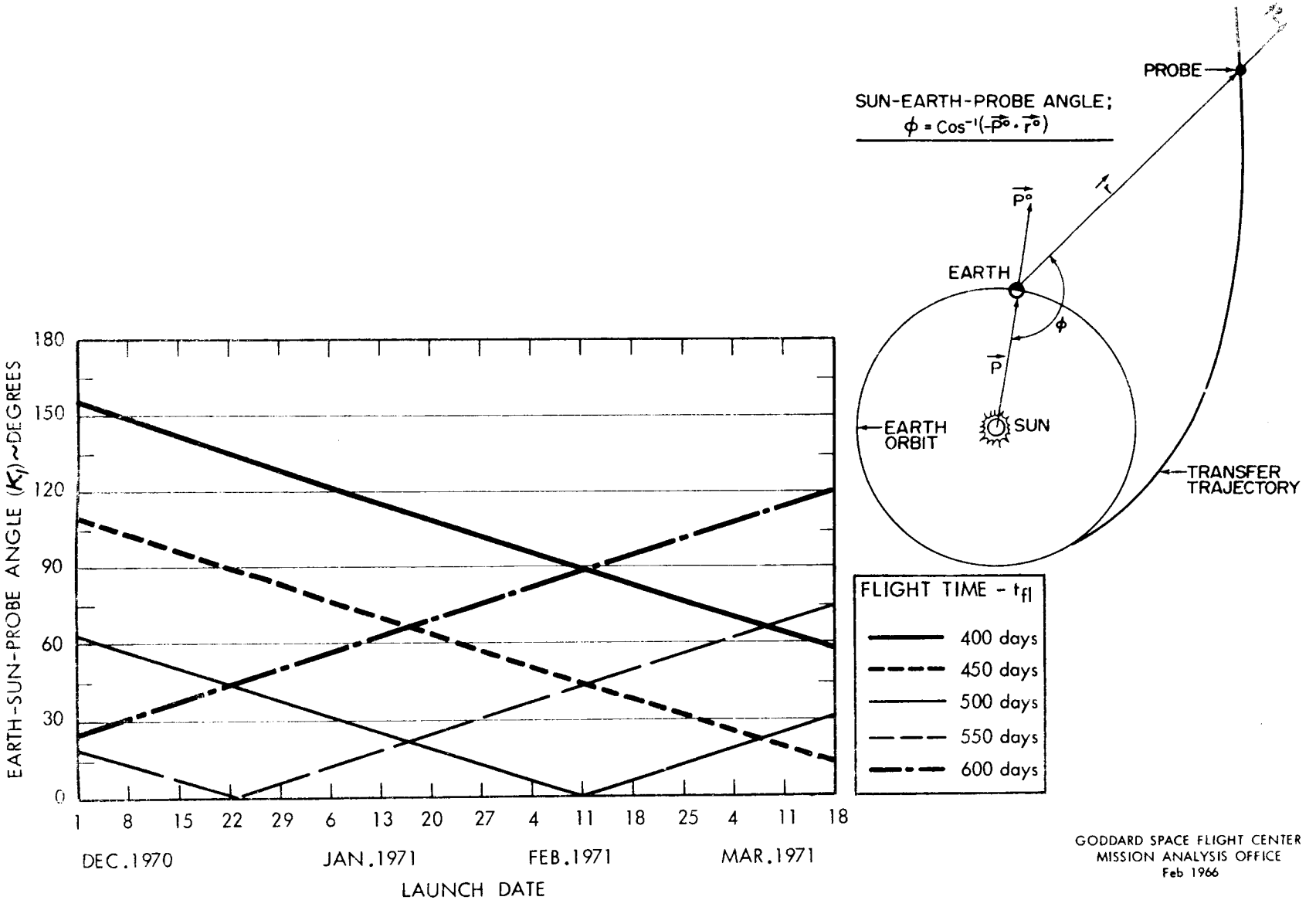

Figure 8b - Earth-Sun-Probe Angle at Arrival versus Launch Date
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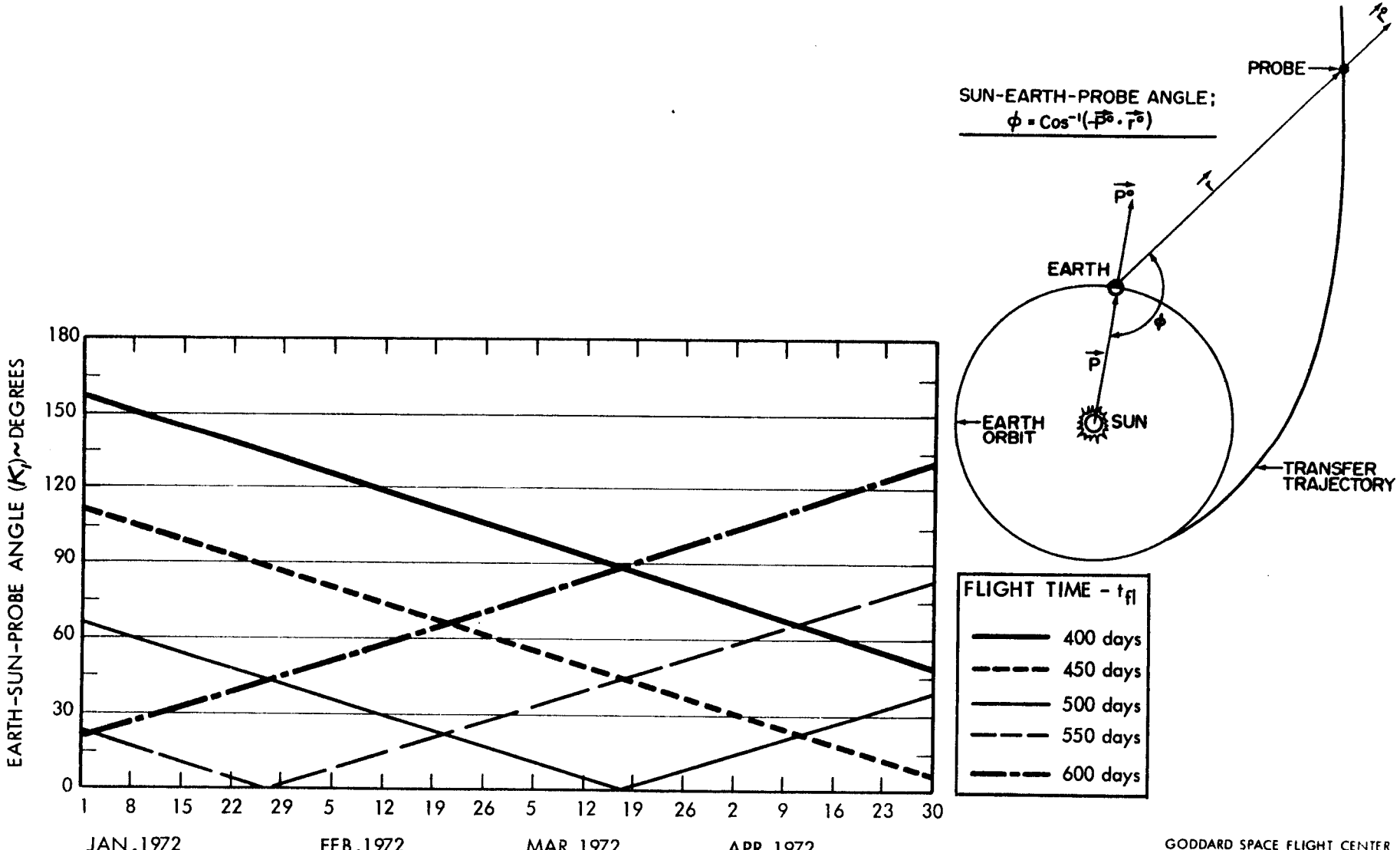

Figure 8c - Earth-Sun-Probe Angle at Arrival versus Launch Date
January 1, 1972 - April 30, 1972

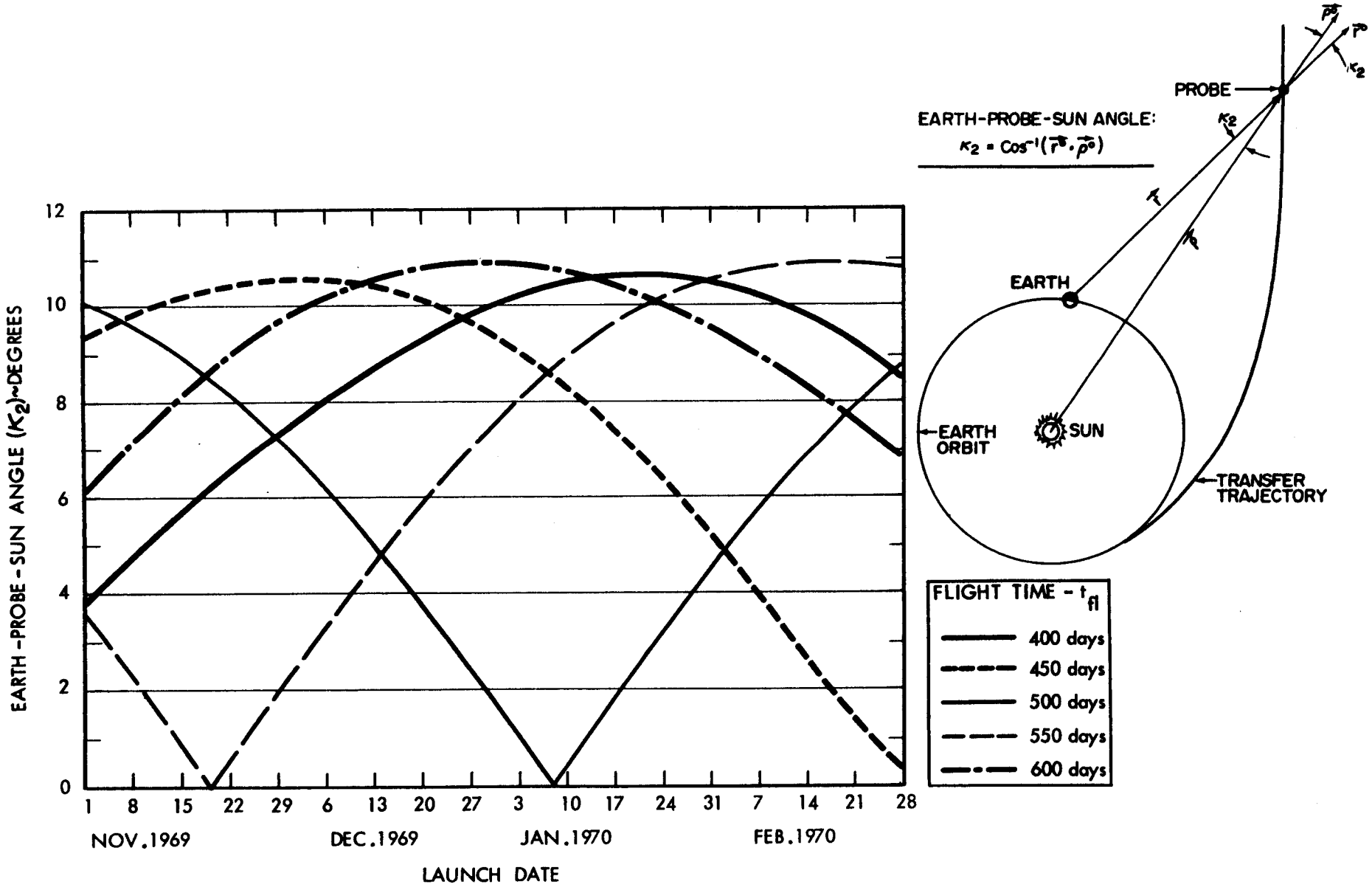

Figure 9a - Earth - Probe - Sun Angle at Arrival versus Launch Date
November 1, 1969 - February 28, 1970

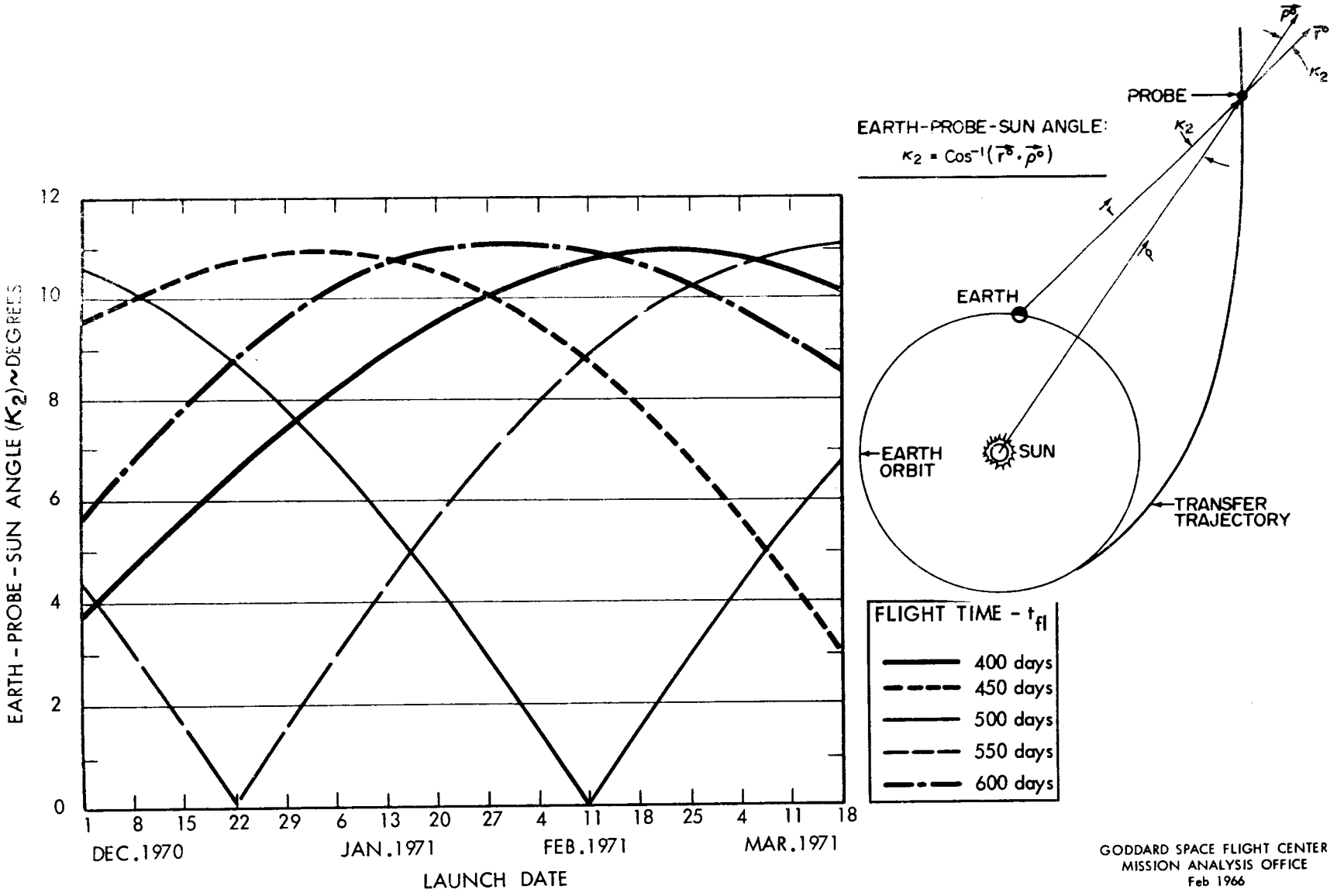

Figure 9b - Earth - Probe - Sun Angle at Arrival versus Launch Date
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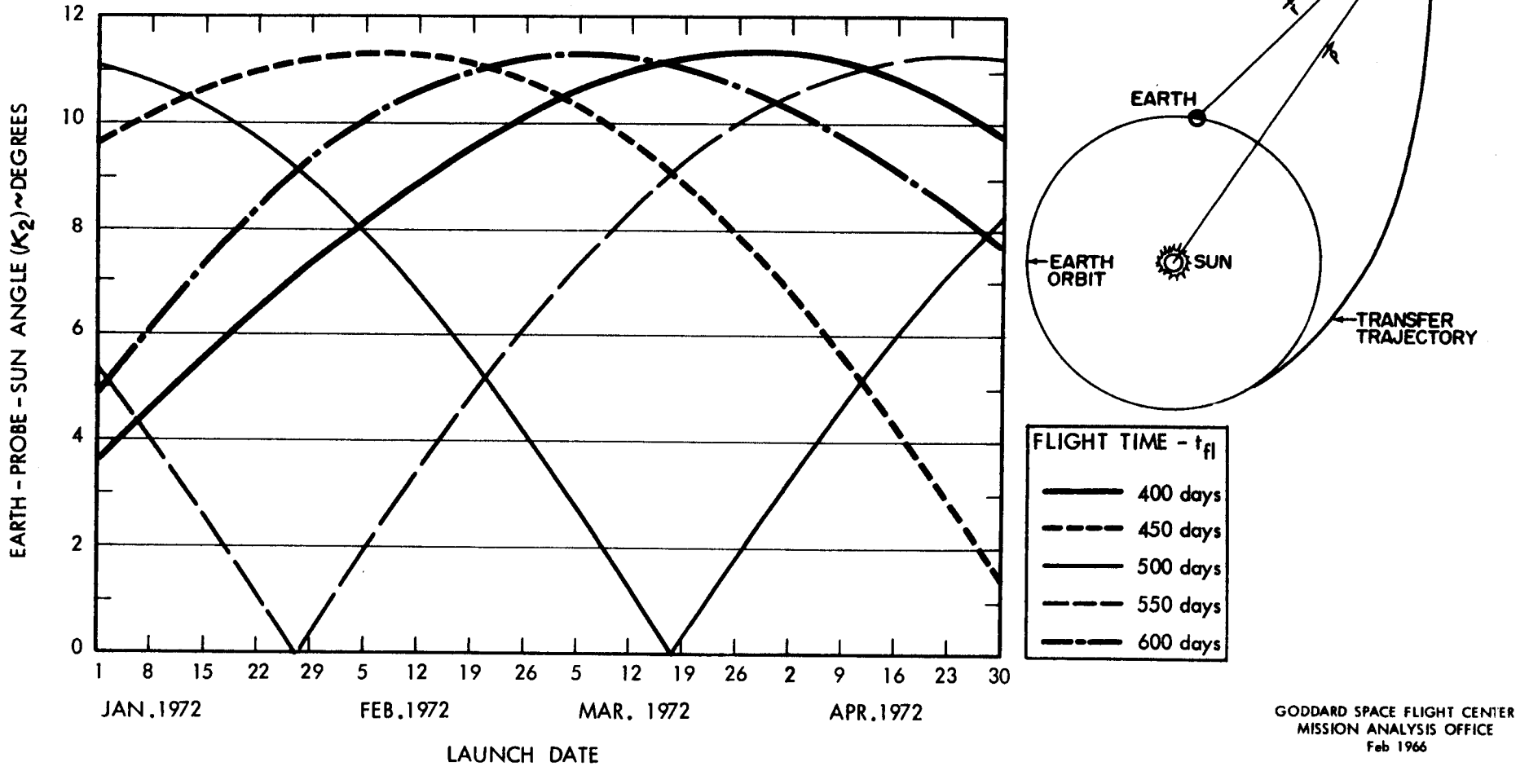

Figure 9c - Earth - Probe - Sun Angle at Arrival versus Launch Date
January 1, 1972 - April 30, 1972

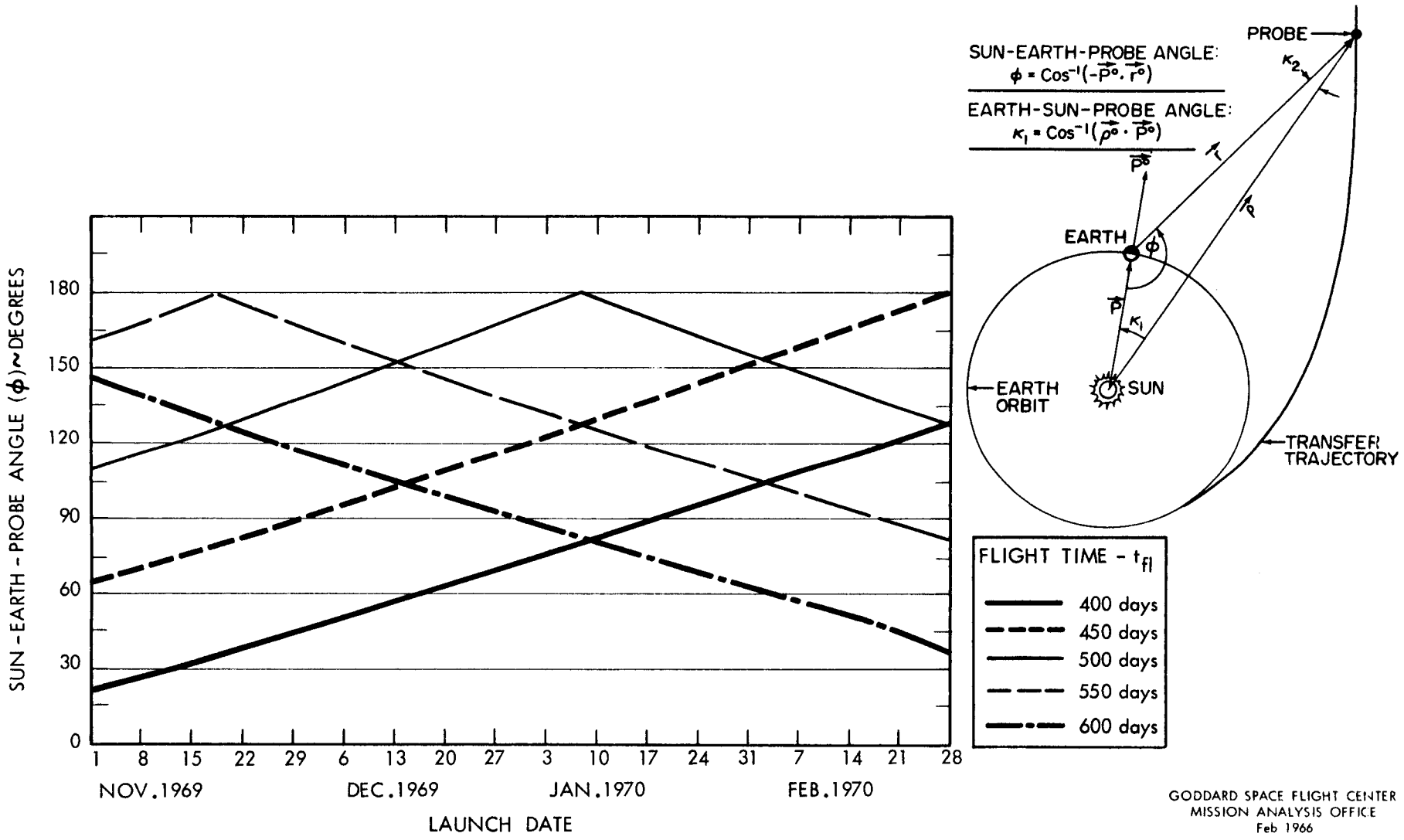

Figure 10a - Sun - Earth - Probe Angle at Arrival versus Launch Date
November 1, 1969 - February 28, 1960

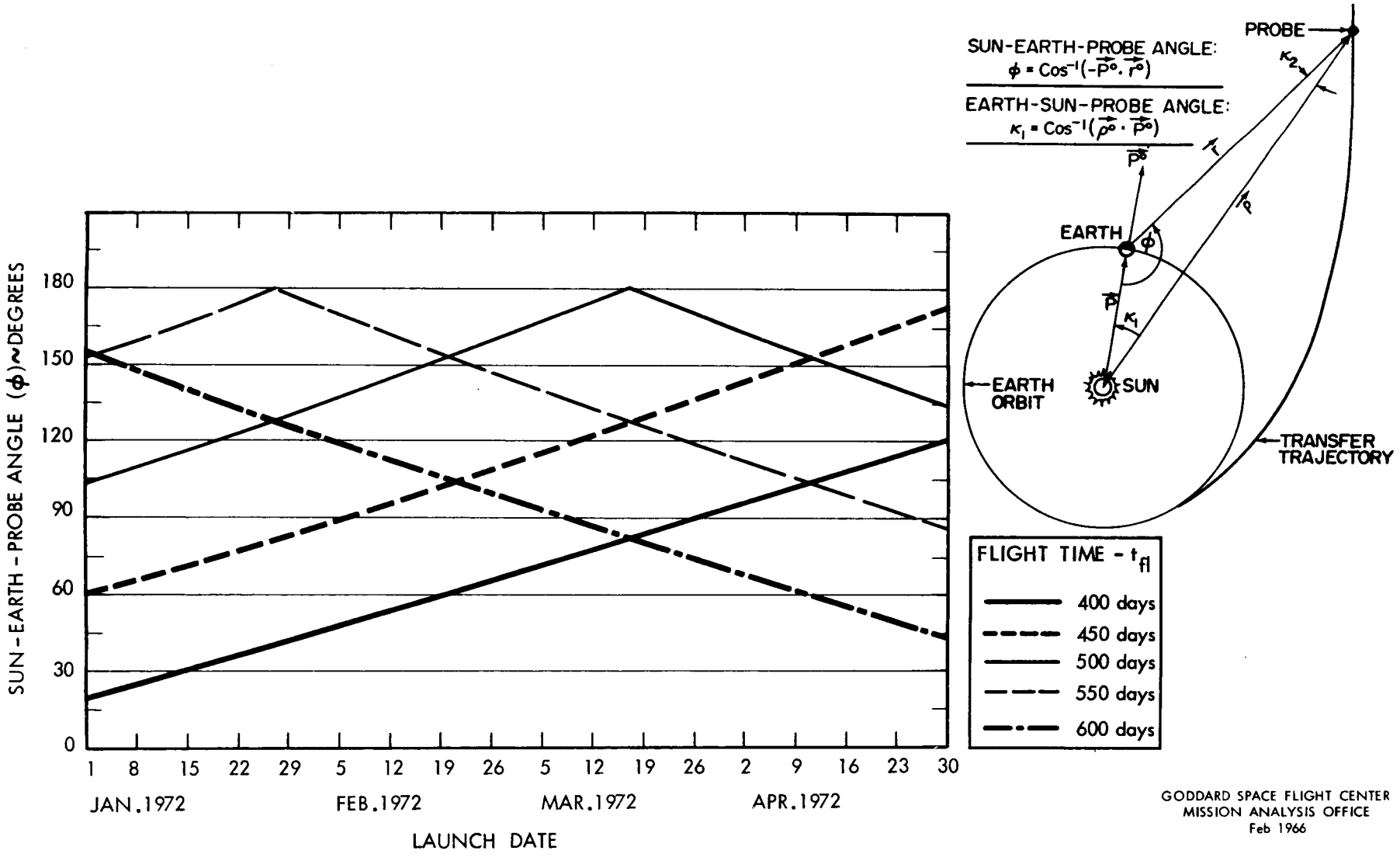

Figure 10b - Sun - Earth - Probe Angle at Arrival versus Launch Date
January 1, 1972 - April 30, 1972

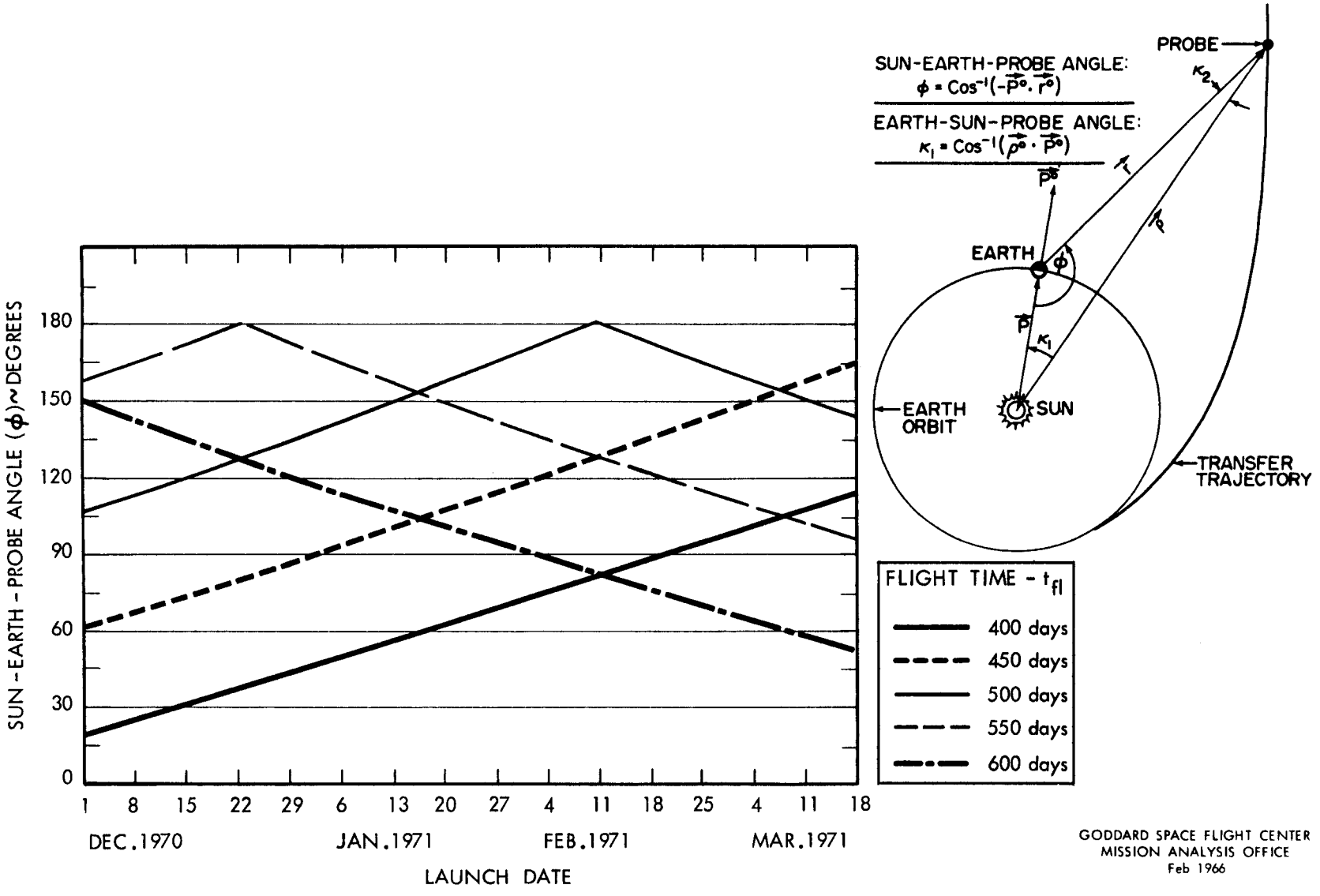

Figure 10c - Sun - Earth - Probe Angle at Arrival versus Launch Date
December 1, 1970 - March 18, 1971